PRACTICAL SHAFT SINKING

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PRACTICAL SHAFT SINKING

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SECOND EDITION

Corrected with two new Appendices

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PREFACE TO THE FIRST EDITION

The subject matter of this book was published as a series of articles in *Mines and Minerals*, during 1909 and 1910. It is reproduced, with some alterations and additions, through the courtesy of Mr. Rufus J. Foster, manager, and Mr. Eugene B. Wilson, editor of *Mines and Minerals*. The writer also wishes to acknowledge his indebtedness to Mr. H. H. Stoek, who was editor of *Mines and Minerals* when most of the articles came out.

September, 1910.

PREFACE TO SECOND EDITION

Since the text of the first edition of "Practical Shaft Sinking" was written, cement grout has been used in several American shafts to cut off flows of water encountered in sinking, and its further use for this purpose will undoubtedly become more common. The writer, therefore, believes that a description of the methods used in grouting off flows of water in two of the city aqueduct shafts (Catskill Aqueduct Project) will make an interesting appendix. Such a description is given in Appendix A. It will be noted that in one of these shafts a stratum of loose sand prevented the entire exclusion of the water by grouting alone, that a concrete lining provided with drain pipes was placed, and that the shaft was finally made entirely dry by grouting this lining.

Several of the city aqueduct shafts in Brooklyn and the lower east side of Manhattan Island were sunk through great depths of water-bearing sand by the pneumatic caisson process. A section of one of these caissons, accompanied

by a description of the methods used in sinking it and sealing it to the rock, is shown in Appendix B.

One change has been made in the shaft records on page 83 to accommodate a new American record. Several footnotes have also been added, and one or two typographical errors corrected.

CONTENTS

PRACTICAL SHAFT SINKING

CHAPTER I

Some Deep Shafts — Features of Contracts for Sinking — Form of Contract

The origin of mining is lost in the mists of antiquity, but it is certain that, since the beginning of history, metals and minerals have been sought after. The Egyptians operated gold, silver, and copper mines in Ethiopia and on the Arabian border; the Phœnicians found gold and iron in the islands of the Mediterranean and lead and silver in Spain. The earliest mines were probably surface workings, but the first historical mention of openings driven in the earth refers not to a drift or tunnel but to a shaft. In the Book of Job it is written of man that "He breaketh open a shaft away from where men sojourn; they are forgotten of the foot; they hang afar from men; they swing to and fro." Pliny describes cutting hitches in a shaft: "Elsewhere pathless rocks are cut away and are hollowed out to furnish a rest for beams. He who cuts is suspended with ropes."

Shaft sinking and tunnel operations in ancient times were confined to solid earth and rock. The Roman engineers drove rock tunnels that would seem long to-day; they originated the method of disintegrating rock by fire and they sunk shafts along the line of their tunnels from which to drive additional headings. Forty shafts — one of them 400 ft. deep — were used for the excavation of their longest tunnel.

For many centuries after the Roman Era nothing comparable to the Roman work was attempted, since the cost in labor and human life of the fire-and-water method was

terrific. The invention of gunpowder was the next step, but gunpowder was apparently not used for blasting purposes until 1679, at Malpas, France. Mines in the Hartz Mountains and in Cornwall had been worked to great depths in the seventeenth century before the steam engine was developed, but its application to hoisting of course made possible undreamed of speed in sinking. The first practical use of steam was, incidentally, to pump water from the Cornish shafts.

The invention of dynamite, the first commercial high explosive, in 1866, and the compressed-air drill in 1855, put rock shaft sinking on its present basis. Although from time to time special methods such as the freezing and the boring processes have been developed for special conditions, for ordinary shafts hand sinking is cheapest and best. Excepting the steam hoist, inventions have been confined to means for shattering the rock; steam shovels are sometimes used in tunnels, but shaft spoil is to-day loaded by hand into buckets, as in the days of the Romans.

Before the last half of the nineteenth century, soft-ground sinking was confined to material penetrable by forepoling. Although considerable depths have been reached in this way, where the ground is bad the method is at best slow and precarious. The Germans originated the hydraulically forced sinking drum and the freezing process. The pneumatic process was first used by Brunel in the Thames Tunnel. Recently, concrete sinking drums or open caissons have been extensively used.

The sizes and shapes of shafts are governed by the nature of the material to be hoisted through them, by the character of the ground to be penetrated, and also largely by local usage. Since mine cars and skips are approximately rectangular in plan, a rectangle is the most economical shape for a hoist shaft, giving the maximum usable area with the minimum excavation; this advantage, however, does not apply to an air shaft. The rectangular shape is also adapted to timbering, the cheapest form of lining, and is on this

account standard in America. In Europe, on the other hand, all shafts are circular or elliptical and are lined with brick or concrete masonry. This type has the disadvantage of high first cost, but a masonry lining is proof against decay and fire and explosions. In wet strata also, a circular shaft may be lined with iron tubbing and thus kept entirely dry.

In large mines two openings are always advisable to secure satisfactory ventilation; in coal mines where explosive gases form they are absolutely necessary, and in most states are required by law. The hoist shaft may be upcast or downcast; in either case an airway is usually provided in addition to the hoist compartments. All mines worthy of the name have balanced cages requiring two hoistways; the airway makes a three-compartment shaft the most common type. In rectangular shafts, where several compartments are needed, a long shaft one compartment wide is easier to sink and timber than a short shaft two compartments wide; for instance, if four 7 × 10 ft. compartments are desired, a shaft 10 × 28 ft. is preferable to one 20 × 14 ft.

In America, in the bituminous coal fields, hoist shafts are usually 13 × 26 ft. in the rock, are lined with 8 × 10 in. timber and have two 7 × 11 ft. hoistways and a 9 × 11 ft. airway. In wet mines a 5-ft. pipeway is added. The air shafts are 13 × 18 ft., with a 10 × 11 ft. airway and a 6-ft. stairway compartment. In the anthracite fields the deeper hoist shafts sometimes have four hoistways operating from several coal seams, besides air and pipe ways, and have sections 12 × 42 ft. to 14 × 56 ft. in the rock. European coal shafts are customarily 20 to 23 ft. in finished diameter. Coal shafts are almost always vertical.

In ore mines different conditions prevail. Ore is less bulky than coal, is harder to mine, and can be loaded through chutes without objectionable breakage. Large shafts are therefore unnecessary and the sizes range from 7 × 9 ft. in the iron mines formerly operated at Boyertown, Pa.,

to 9×24 ft. in the Michigan iron country. Ore shafts are usually sunk on the vein, and so may be found at any inclination with the vertical, but where natural conditions do not compel an inclination, a perpendicular shaft is preferable.

The deepest shaft in America, No. 3 Tamarack at Tamarack, Mich., is 5253 ft. deep and is used in mining copper. No. 5 shaft at Tamarack is 5180 ft. deep, Red Jacket shaft at Calumet, Mich., is 4900 ft. deep. These shafts are remarkable not only because they penetrate the earth for almost a mile, but also because of the remarkably powerful hoisting engines used — engines which hoist a total load of 17 tons at the rate of 6000 ft. per minute. All of these shafts are vertical.

In the Pennsylvania anthracite fields, where acid mine water quickly eats up pumps and piping, a number of shafts have been sunk for the purpose of hoisting water. The tanks used for hoisting fill and empty themselves automatically, discharging the water into a basin at the top of the shaft. Powerful hoist engines are provided. The most notable shaft of this type is owned by the D. L. & W. R. R., at Scranton, Pa. It is entirely automatic, requiring no engineer, and is operated through friction clutches by an 800-horse-power induction motor.

The driving of rock shafts and tunnels is very unlike the mining of coal; a different class of workmen, different foremen, and different tools are needed. It is seldom that a good coal-mine foreman is also a good sinker, and good sinkers, unattached, are not always easy to obtain. For these reasons it is customary for coal-mining companies to have a large part of their development work done by contract, and even the large anthracite corporations, who own the necessary surface equipment for sinking, prefer to have contractors do the sinking. In ore mines the foregoing does not apply; sinking shafts is part of the day's work and all the miners are rock men, but in opening a new mine the question of time is still to be considered. The loss of

interest on the investment in a large property before it is developed may amount to several hundred dollars a day, and every day lost in sinking adds that much to the cost of the shaft. Even when a mining company is so situated that it can sink its shaft cheaply, a responsible contractor possessing a plant and an organization can save enough time to more than pay his profit.

When it is decided to have a shaft sunk by contract, the first essential is to get trustworthy contractors to bid on the job; the second is to prepare a contract fair to both sides. While it is not well to leave loopholes whereby the contractor can escape from the plain provisions of the specifications, it is equally unwise to attempt to tie him down so tight in every detail that he is practically dared to find a flaw in the agreement. It is almost impossible to foresee every contingency, and an omission in a very tightly-drawn contract is harder to correct subsequently than an omission in a looser one.

A complete shaft contract form may be found in several text-books, or obtained elsewhere without difficulty; a form in common use is appended to this chapter. Among the specific points that warrant attention may be mentioned the following:

Disposal of Spoil. — The labor cost of a shaft is of course directly affected by the nature of the dump. It is also indirectly affected by it to an even greater extent. The delays to sinking caused by a long haul and an inconvenient dump, especially in bad weather, are likely to be more serious than the cost of the additional labor required. The specifications should, therefore, state where the spoil is to be dumped, or at least where it is not to be dumped. In one case where a contract contained the usual clause, "the spoil shall be placed where the engineer shall direct, the haul not to exceed 1500 ft.," no plans were available, and in the absence of any direct prohibition by the engineer, the contractor started to dump spoil in the vicinity of the shaft. After three months' sinking, the engineer discovered that

the dump was in his way and directed that the spoil be placed elsewhere. Subsequently he compelled the contractor, under the clause cited above, to move all the spoil dumped in the first three months. While in this case the engineer's order might have been successfully contested, much trouble could have been saved by proper care in drawing up the contract.

Time Limit and Penalty. — A time-limit clause is most properly a feature of nearly all sinking contracts, and the usual provision made to secure its enforcement is, "and in the event of the contractor failing to complete the work by this date, it is mutually agreed that he shall pay the contractee the sum of —— dollars for every day thereafter until the work is completed, not as a penalty, but as liquidated damages." In spite of this definition, the courts have often held that the actual damages must be proven and the possibility of collecting the stated damages is not assured. Since the real damages to a mining company due to delay in getting started consist of the loss of interest on the investment, in every case where the company has its surface arrangements ready for work before its shafts are finished, it will gain as much per day by their completion ahead of time as it will lose by their non-completion. The writer therefore believes that where a penalty is to be collected for delay an equal premium should be paid for time saved, not only because this is fair but also because it is likely to expedite the work. An extension of time is usually, and should be, allowed the contractor on account of "unusual difficulties with water or quicksand."

Acceptance. — Where two shafts are sunk simultaneously under the same contract (as in opening a new coal mine), the first shaft down is usually accepted by the company upon completion. If this is not the intention it should be so stated in the contract.

Risk of Water. — It has been the practice in shaft contracts to throw the risk of encountering unusual quantities of water upon the contractor. With a fixed price per foot

for sinking, based upon usual conditions, the contractor will lose money if he strikes water exceeding, say, 150 gallons per minute. With greater quantities his loss is often measured only by his financial resources. This puts a responsible contractor at a disadvantage, especially in a new territory, for since he has the equipment and the money needed to fight large quantities of water, he must raise his price on all shafts to insure him against an occasional heavy loss. An irresponsible contractor, on the other hand, having little to lose, can afford to bid low, and if he does strike much water abandon the job. The water risk belongs properly not to the contractor nor the mine owners in general, but to the owners of the particular mine in question; for this reason a water clause is a feature of many recent contracts. The New York Board of Water Supply, in its contracts for the construction of the inverted siphons on the Catskill aqueduct, calls for a price for pumping each million gallons of water 1 ft. In these jobs the time schedules are so carefully worked out that there is little likelihood of the contractor pumping water for profit, but a form of water clause more acceptable to the average mining company is one in which the contractor makes an additional price per foot for every hundred gallons per minute pumped while sinking. He is thus paid nothing if the shaft is idle and is encouraged to make progress.

Supplies and Machinery. — Local conditions determine whether the mining company or the contractor should furnish the supplies or machinery. The larger anthracite companies, who hold extensive properties and open new mines upon them as the need arises, own sinking engines, boilers, and other equipment; at a new shaft they erect a surface plant complete, furnish timber and coal, and expect the contractor to supply only the air compressor and drills, small tools, and labor. In the bituminous fields and in many ore regions, the mining companies usually wish to develop new property as soon as it is acquired, and, in order to concentrate their efforts upon the permanent surface

plant, expect the shaft contractor to furnish everything he needs. A quicker start can be made in this way. If the shaft is to be timbered, however, the timber should be furnished by the company. Oak suitable for shaft linings is rapidly becoming unobtainable; yellow pine must be brought long distances and is not likely to arrive too soon if ordered when the shaft contract is let. Aside from the question of speed, the company by supplying timber will save itself the profit that the contractor adds to cost, and also occasional vexatious squabbles as to quality.

No matter how the shaft is sunk the permanent boiler plant should be made ready to operate as soon as is practicable. The possibility of striking water is the greatest hazard of sinking and, if water is encountered, the first requirement is plenty of steam. It is easier and quicker to procure and install any amount of pipe and any number of pumps than it is to build a boiler plant to run the pumps. Effective sinking pumps are so exceedingly wasteful of steam that the permanent mine boiler plant will be none too large and efficient to care for a large inflow of water; its early completion will insure against a long and costly delay.

The local flow of underground water is one of the most uncertain features of geology, and whether or not water will be encountered in a given shaft can seldom be predicted with certainty. Even when borings at the site of a shaft or other shafts sunk in the vicinity indicate that water will be struck, the amount is problematical. A few general remarks may be stated as follows:

Since the rainfall in mountains is high, the ground near them will have an opportunity to collect water. Geologic faults form passages whereby surface water finds its way into the ground, and the fissures caused by the strain to which the rock was subjected when the fault was made act as reservoirs. A shaft on or near a fault is sure to be wct below the ground-water level of the surrounding region. Natural water courses also form in soluble rock such as sandstone and limestone, especially the latter. An example

of a water course of this kind was afforded at the zinc mine at Friedensville, Pa., formerly drained by the "President," the largest Cornish pump ever built. This mine is located at the foot of a mountain.

Two shafts sunk in the Allegheny Mountains near South Fork, Pa., also encountered a water course. They were about 250 ft. apart and apparently were sunk directly on top of the water channel. What may be called the down-stream shaft was sunk first through the wet stratum; as the up-stream shaft was sunk the flow into it increased, while the flow into the down-stream shaft decreased at the same rate.

Shafts near streams are likely to strike water at the surface of the rock, but not necessarily below it if the rock is solid. In ordinary coal measures a feeder may be expected at the seam between an upper permeable rock like sandstone, and a lower bed of impervious shale or fireclay.

The uses of the diamond drill in prospecting for coal and ore are too well known to require comment, as far as the knowledge obtained of the rock is concerned. A hole near a proposed shaft will also give much information as to the ground-water conditions, even though, as has been said, the quantity cannot be determined. A diamond drill hole is not large enough to pump out, but the process may be reversed. If additional water can be pumped into a hole already full, the strata are evidently open enough to let water into a shaft. A bore hole, of course, may be pumped with a deep-well pump or air lift; it has in fact been suggested that wet ground be drained by pumping from a ring of bore holes around the shaft location, thus doing away entirely with pumps in the shaft.

Prospect holes should be located at one side of the shaft, so that if a pocket of water is drilled into at a considerable depth, it will not rise into the shaft through the hole. In this way pumps and piping need not be installed until the bottom of the shaft has almost reached the level of the pocket, and the depth of the wet sinking is reduced to a minimum.

CONTRACT AGREEMENT FOR SHAFT SINKING

This agreement made in duplicate this day of by and between the Coal Co., a corporation chartered and existing under the laws of the State of party of the first part, and . the Contracting Co., a corporation chartered and existing under the laws of the State of , party of the second part,

WITNESSETH, That for and in consideration of the covenants and payments hereinafter specified to be made and performed by the party of the first part, the said party of the second part doth hereby covenant and agree to build and complete in the most substantial and workmanlike manner, a hoisting shaft 13 × 26 ft., outside the timbers, and an air shaft 13 × 18 ft., outside the timbers, each approximately 600 ft. deep, for the Coal Co., at its property near . The work is to be done in accordance with the attached specifications and the plans furnished by the party of the first part, which are hereby made a part of this agreement; the party of the second part is to furnish all the labor and materials necessary, except such as are particularly noted in the specifications as being furnished by party of the first part.

The said work is to be completed on or before the first day of , 19 .

And the party of the first part doth promise and agree to pay the party of the second part the following prices for the several kinds of work herein specified, of which the following is a summary:

HOIST SHAFT

Excavation measured from top of natural ground to bottom of coal seam	$	per vert. ft.
Framing and placing all timber and lagging	$	per vert. ft.
Water rings complete	$	each.

AIR SHAFT

Same as above.

The above prices contemplate a maximum of not more than 100 gallons of water per minute to be pumped from each shaft.

The following extra prices will be paid in each shaft for each 100 gallons per minute in excess of this amount, as follows:

Water Pumped; Gallons per Min.	Additional Price Paid per Foot
100 – 200	$ 15
200 – 300	30
300 – 400	45
400 – 500	60
500 – 600	75
600 – 700	90
700 – 800	110
800 – 900	130
900 – 1000	150

If the volume of water should exceed 1,000 gallons per minute, a supplementary agreement will be made.

The payment for said work shall be made in the following manner:

An estimate will be made about the last day of every month of the amount of work done during the month, and 90 per cent. of the same will be paid on or before the 20th of the succeeding month, 10 per cent. of the total amount being retained until the entire completion of the work.

And when all the work embraced in this contract is completed, the party of the first part shall, upon notification from the party of the second part, make a final inspection; if the work is found to be in accordance with the specifications, there shall be a final estimate made of the value of said work, according to the terms of this agreement. The balance due the party of the second part shall be paid within thirty days thereafter, upon said contractor giving a release under seal to the party of the first part from all claims or demands whatsoever growing in any manner out of this agreement; and upon said contractor delivering to party of the first part full release in proper form and duly executed of all liens, claims, or demands from mechanics

and material men for work done on or about the shafts, or for materials furnished for the work under this contract.

It is further agreed between said parties that said party of the second part shall not transfer or sublet any part of this contract to any person (except for delivery of materials) without the consent of the party of the first part, and that the party of the second part will at all times give personal attention to the superintendence of the work.

It is further agreed that the work embraced in this contract shall be commenced within two (2) weeks of the date of this contract and prosecuted day and night (except Sundays) with as many men as can be worked to advantage. If, during the progress of the work, it is the opinion of the Engineer of the party of the first part that the party of the second part is not furnishing materials or appliances or labor of the right quality, or in sufficient quantity to complete the work within the time agreed on, the said Engineer may in either or both of the above-mentioned cases purchase such material and appliances or employ such labor as in his judgment may be necessary. And the said Engineer is authorized to pay such wages for labor and such prices for materials and appliances as may be found necessary or expedient, and to deduct the amount so paid from any moneys due the party of the second part from the party of the first part.

It is further agreed that the Engineer shall have the authority to order any additional work or materials not called for in the plans and specifications that he may deem necessary or advisable, but in case any such extra work or materials is required, the same shall be ordered by the Engineer in writing, and the price for said extra work or materials shall mutually be agreed upon in writing before said materials are furnished or said work is done.

IN WITNESS WHEREOF the parties herein have hereunto set their hands and seals, the day and date first above mentioned.

Specifications for Sinking and Lining Two Shafts for the Coal Company, at

GENERAL

Meaning of Titles. — The word Contractor, when hereinafter used, shall refer to the Contracting Company as in the attached Agreement. The word Engineer shall refer to the Chief Engineer of the Coal Company, or his representative.

Labor and Materials Furnished.— The Contractor shall furnish all machinery, tools, labor, materials, and supplies incidental to, or in any way connected with, the sinking and timbering of the two shafts hereinafter described, with the exception of the timber which will be furnished by the Coal Company free on board cars at .

Location of Temporary Plant. — The Contractor's hoisting apparatus and temporary machinery and buildings shall be so placed as not to interfere with the construction of the permanent head-frames, or the erection of the permanent plant.

EXCAVATION

The dimensions of the hoist shaft shall be 13 × 26 ft. and of the air shaft 13 × 18 ft., outside of lagging. The excavation shall be carried down square and plumb from top to bottom and be large enough to give room for the proper wedging of the timber. Special care must be exercised in blasting to avoid shattering the walls of the shaft, and all loose material which might endanger the timbering or the men working below must be removed.

The Contractor shall keep his machinery and tools in good condition, and take every reasonable precaution to insure the safety of his men.

The Contractor shall deposit all material excavated from the shafts at places directed by the Engineer, to conform to the grades established adjacent to the shaft. Any overhaul exceeding 500 ft. shall be paid for at the rate of cents per cubic yard for each 100 ft. of overhaul.

The depth of the shafts shall be measured from the elevation of the original surface of the ground in the center of the shaft to the bottom of the coal seam.

TIMBERING

The shaft shall be timbered throughout with sound oak or yellow pine to be furnished by the   Coal Company. It is to be framed accurately by the Contractor according to the Coal Company's plans and shall be placed in the shafts square, level, and to line.

Wall plates, end plates, buntons, and posts shall be 8 × 10 in., and bearing or hitch timbers shall be 8 × 12 in.; lagging shall be of 2-in. plank. The lagging shall rest on a 2 × 4 in. oak piece placed horizontally in the middle of the back of each end and wall plate and well spiked; the space between the lagging and the rock shall be backed solid with sound slabs or other sound refuse timber.

Each corner of each ring of timbers and each wall plate at both ends of every bunton shall be thoroughly braced against the side of the shaft by blocks and wedges. The sets of timber shall be 5 ft. apart vertically, center to center. At intervals of 50 ft. vertically, bearing or hitch timbers shall be placed to serve as supports to the timbering above. The hitch or bearing in the rock at each end of each timber shall be strong enough to develop the full strength of the timber; in no case shall it be less than 8 in. in depth. The intervals of 50 ft. may in the judgment of the Engineer be varied, but no such variations shall be made by the Contractor without the consent of the Engineer.

The timbering shall be carried above the natural ground to the level indicated by the Engineer. Special timbering shall be placed at the shaft bottom in accordance with the plans furnished.

The air compartment shall be lined with 1-in. tongued and grooved yellow pine flooring, free from knots and well matched and joined on end and wall plates. The guides shall be 6 × 8 in. yellow pine surfaced on all faces, and shall

be framed as shown on plan and placed exactly plumb, and straight and true to gage from top to bottom.

WATER RINGS

The water rings shall be constructed before the timbering is finally placed, and shall be as shown on the plans. The bottom of each ring shall have a water-tight floor of concrete. The number and location of the water rings shall be determined by the Engineer.

USE OF CONTRACTOR'S PLANT

The Coal Company shall have the privilege of renting the Contractor's hoisting and pumping plant after the completion of the shafts for a period of two (2) weeks. It shall pay the Contractor $ per day as rental for said plant.

CHAPTER II

Plant Required — Boilers, Hoisting Engines, Headframe and Buckets — Air Compressors

PLANT

In considering the subject of shaft sinking from the mechanical side, the first and most important consideration is the proper design and arrangement of the surface plant. The underground plant comprises rock drills and pumps, and both above and below ground many tools and contrivances are required. The items included under surface plant will be treated first and the underground contrivances taken up later in connection with the work which they perform.

The elements of a modern surface plant are: Primary-power producer; hoisting apparatus; secondary-power producers; buildings, shops, etc.

Primary-power Producer. — Although in a few favored localities electric power may be cheaply bought and used directly, or converted into air power when needed, in nine tenths of the shafts sunk the primary power is steam. The boiler plant, in this case, is the backbone of the job; it must be put up to allow of expansion if necessary, and it must be absolutely reliable. In other forms of construction work, water, while always a source of trouble and expense, is not the implacable enemy that it is in sinking. The pumps which drain a cofferdam will also serve to empty it, and a breakdown delays the work only until repairs are made. In a wet shaft, on the other hand (particularly where the ordinary types of sinking pumps are used), an hour's lack of steam may submerge the pumps and allow the shaft to fill. It will then be necessary to get new pumps and piping and to fight the water down again from the top, and

weeks or months may elapse before sinking can be resumed.

For a wet shaft or for any shaft deeper than 250 or 300 ft., the bricked-in return-tubular boiler is the most satisfactory type. Such a boiler burns under normal firing 15 to 20 per cent. less coal than the ordinary portable boiler. The difference in the coal bill for 100 boiler horse-power, with coal at $4.50 a ton, will, therefore, in three months, amount to $300, which is about the cost of bricking in a 100 horse-power return-tubular boiler. The latter also costs less for repairs and is generally less trouble than the portable boiler.

For a short job the oil well, or locomotive type, boiler is the best. The size should be not smaller than 40 horse power; 60 horse-power is better, as in the small sizes the crown sheet has such a shallow covering of water that it is easily burned. The dome should be placed on the barrel of the boiler; if over the crown sheet, the long stay bolts connecting the crown sheet and the top of the dome are likely to give trouble. By utilizing the exhaust from a compressor or hoist engine, it is possible to force the locomotive boiler to make steam greatly in excess of its rated capacity, and this fact gives it a great advantage over other types.

At coal shafts the boilers should be set far enough away to make it impossible for a sudden flow of gas from the shaft to become ignited. They should always be placed so as to minimize the cost of handling coal and ashes. The ground at one end of the line of boilers should be clear of buildings or machinery, to allow of additional units being placed as required.

The piping should also be arranged to permit expansion, not only of the plant as a whole, but also the temperature expansion of the pipe itself. At the open end of the line of boilers the header should terminate in a valve, so that the additional boilers can be coupled on without shutting down the plant; if so many boilers have to be added that a second header is necessary, it should be connected with the first at both ends, forming a steam loop. Stiff connections between

the boilers and the header are objectionable and are likely to cause leaky joints.

A constant supply of feedwater must be assured. Duplicate feed-pumps or injectors, or a combination of the two, should be provided, and the pumps supplying water from a stream to the supply tank should also be in duplicate.

A good feedwater heater will cut the coal bill surprisingly; to be accurate, 1 per cent. for every 10 degrees the feedwater is raised. Assuming the feedwater at 50° F., originally, an open heater with plenty of exhaust steam will raise its temperature to 210° and reduce the fuel consumption 16 per cent. With coal at $4.50 per ton, a heater will pay for

FIG. 1. — Ingersoll-Rand Two-stage Straight Line Air Compressor

itself in two months. An open heater as shown in Fig. 1 is more efficient than a closed heater and maintains its efficiency; it has no tubes to leak and become covered with scale; it saves the pure water formed by the condensed exhaust steam, and it is adapted to various systems of water purification. It must, however, be used in connection with a good separator for removing the oil from the exhaust.

A satisfactory feedwater system for a plant containing several boilers may be arranged as follows: Feed all boilers from a common header. Provide regulating valves, in addition to regular check- and boiler-stop valves in connections between header and boilers. Supply water to header with pump large enough to feed all boilers with piston speed of 50 ft. per minute. Use hard rubber, or

metal, pump valves. Use an open heater, placing it with base 6 ft. above the pump. As a reserve provide enough injectors to feed the boilers when the pump is shut down, connecting them into the feed-header. Provide valves between each injector and header, and between pump and

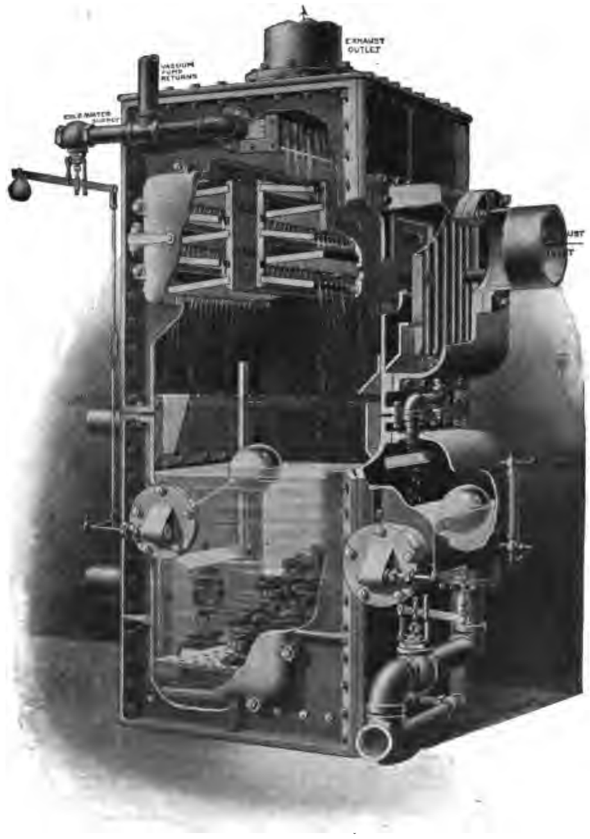


Fig. 2. — Cochrane Feedwater Heater

header. Take steam connections for injectors and pump from main steam line. Where freezing weather is possible, bury all outside water lines.

An ample power supply for a single dry shaft is 100 boiler horse-power. For a wet shaft the power required depends on the quantity of water to be pumped. Three

thousand boiler horse-power has been used for three very wet shafts, only two of them being worked at simultaneously.

Hoisting Apparatus. — For sinking a shaft through the surface soil, a small stiff-leg derrick is usually erected. This makes excavation and timbering cheaper than if done by hand, and it does not interfere with placing the surface concrete or add weight to the ground around the shaft. A derrick with a 40-ft. boom and a 30-ft. mast, built of 12 × 12 in. timber, is large enough for sinking. It can be readily swung by two men at the end of a 10-ft. lever bolted to the mast. If any considerable depth is to be sunk, this lever should be secured by some kind of latch to prevent the derrick swinging while the bucket is in the shaft.

A double-drum friction engine is best for a derrick as it enables the engineer to raise and lower the boom, and also, with the help of a winchman, to swing the derrick; 7 × 10 in. and $8\frac{1}{4}$ × 10 in. are convenient engine sizes. A single-drum sinking engine may be used to advantage on a derrick with a fixed boom swung by hand. The fall line sheaves should be larger than are ordinarily used for a light derrick; never less than 18 in. outside diameter, preferably 24 in. A $\frac{3}{4}$-in. rope will work over a 24-in. sheave without undue wear.

Although a small shaft may be readily sunk with a derrick for 200 ft., it is better to put up a head-frame when the surface timbering or masonry is completed. Sinking head-frames are often built unnecessarily large and heavy. A head-frame 40 ft. high and 8 × 12 ft. in plan is large enough for a sinking shaft. It may be built of timber, with 8 × 8 in. posts, 3 × 8 in. diagonal braces, 8 × 10 in. caps, and 10 × 12 in. sheave timbers, as shown in Fig. 3, or, if it is to be frequently moved, of steel. If built of steel, 6 × 6 × $\frac{1}{2}$-in. angles will form posts strong enough to handle with safety a 5-ton pump. The sheave, as a rule, should not be smaller in diameter than the engine drum, but a 48-in. wheel will give good service with 1-in. rope.

Two methods are used for the disposal of the spoil hoisted by the head-frame. In the first a broad-gage

track is extended under the frame so that the rope passes between the rails; when a full bucket has been hoisted above the track, a truck carrying an empty bucket is pushed under it, the full bucket is set on the truck, and the empty one lifted. The truck is then pushed away and the bucket dumped by a gallows frame or other device. Three buckets are needed for this method so that one may be always in the bottom.

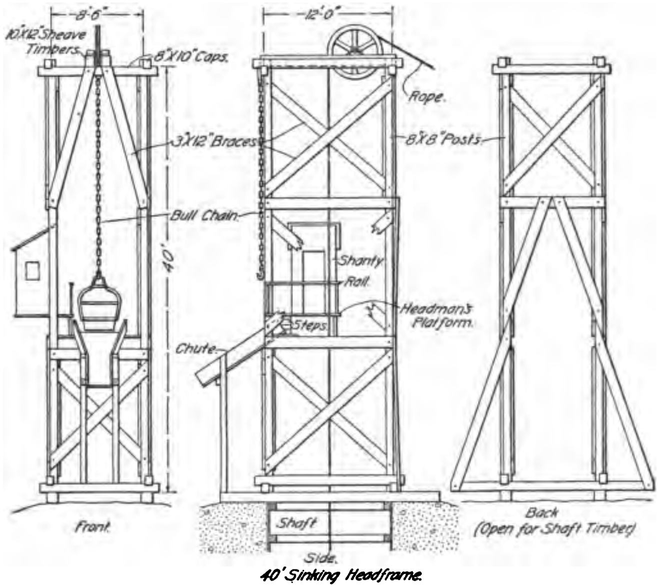


FIG. 3. — Sections of Sinking Head-frame

In the second and better method, tipping buckets must be used. At one side of the head-frame a chute is built, high and long enough to discharge spoil into a dump car, its upper end just clearing the bucket hanging free on the rope, Fig. 3. On the cap above the chute a "bull chain" is hung. The "head-man" stands on a platform level with the top of the chute and, when the bucket is hoisted within reach, hooks the bull chain into the bail. The bucket is lowered slightly, swings out over the chute, and is dumped. The complete operation may be performed in 30 seconds.

This method requires only two buckets. Three-quarter inch common chain will serve for the bull chain. Its hook should be provided with a handle. At a deep shaft, the bottom of the chute should be covered with pieces of old rail laid lengthwise, and in rock that breaks into large lumps a gate is advisable to protect the dump car. A small house is usually built for the head-man at the platform level.

To facilitate hooking the shaft rope to the bucket, 3 or 4 ft. of chain is inserted between the rope and the hook. The chain should be welded into a closed socket babbitted to the rope, and its links should be 6 in. long so as to afford a good hand grip. Safety catches are provided on the hook.

Shaft buckets are circular in plan and contain from $\frac{1}{2}$ to 1 cubic yard, depending on the depth of the shaft and the size of the engine. A flared bucket, Fig. 6, discharges rock more freely than a cylindrical one; a convenient size is 3 ft. 6 in. top diameter and 2 ft. 10 in. bottom by 2 ft. 9 in. high. The bail is secured to the bucket trunnions by straps and bolts, so that it may be easily removed for repairs. A wooden inner bottom is sometimes used to cushion the blows from pieces of rock. Every bucket should have two latches, and two lugs to prevent its dumping in the wrong direction.

The dump car that will not be knocked to pieces by large rocks falling from the chute must be very strongly built. Its other qualifications depend on the nature of the dump. Ordinarily, where the dump is close to the shaft, and the car is pushed by hand, a 36-in. gage, all-around dump car, with wheels loose on the axle, is best. The simpler the construction the better.

A cheap and easily erected head-frame, for use when the regular plant is not available, consists of a tripod made of three poles bolted together at the top. This is set up over the excavation, a snatch block is attached at the top and another at the foot of one of the legs, and small buckets are hoisted by a team of mules, pulled to one side and dumped

on a platform by hand. The buckets are made out of a half oil barrel, fitted with extra hoops and a bail.

For depths of less than 500 ft., an 8¼ × 10 in. double-cylinder end-friction hoisting engine with a 41-in. drum will do satisfactory work. The friction and brake levers are most convenient if set in a stand back of the drum, as is customary with larger engines. Both should have latches; on the brake lever a latch is imperative. An engine of this size will hoist a loaded bucket weighing 2500 lbs. 350 ft. in a minute; a round trip from this depth, including dumping the bucket, can be made in two and a half minutes.

At depths greater than 500 ft., the weight of the rope and the long hoist make a larger engine necessary. Reversible link-motion geared engines similar to that shown in Fig. 7 are generally used, the sizes varying from 10 × 12 in. to 14 × 20 in. First-motion engines are sometimes used for great depths. A 10 × 12 in. geared engine running at a speed of 400 ft. per minute has a hoisting capacity of 4500 lbs., and will handle muck from a depth of 800 ft.

The drum should be grooved so that the rope will wind regularly and not cut itself. The size of rope used for sinking runs from ¾ in. up, but sizes greater than 1 in. are unnecessary. A 1-in. crucible cast-steel rope has a breaking strength of 34 tons; it weighs 1.58 lbs. per foot, and therefore, when hoisting a 3000-lb. bucket, has a factor of safety of 11 at a depth of 2000 ft. This factor is ample, and there is no use in consuming power in hoisting additional weight.

Many lives depend on the brake of a sinking engine, and it should, therefore, be made large and strong beyond possibility of fracture. In the case of a band brake, the diameter of the part of the drum gripped by the band should be as great or greater than that of the drum itself, and the lever should tighten the band in the direction of the pull of the rope, the other end of the band being rigidly attached to the frame of the engine. A good brake, capable of stopping the drum every time within an inch of the mark, is not only a safeguard, but a great assistance to sinking,

especially in setting up the bar and machine or in handling timber.

Double-drum engines, necessarily friction operated, are built for sinking purposes, one drum being used for the bucket, the other for handling pumps, piping, etc. The second drum introduces another set of gears, causing additional friction and wear, even when running idle, and costs as much as a small independent engine, which is in every way preferable. A compound-geared, reversible link-motion engine, of the type used for swinging derricks, makes a good engine for handling pumps. The 7×8 in. size will hoist 7000 lbs. on a single rope. The engine can be started and stopped just where desired, and there is no danger of a heavy load getting out of control.

Electric hoists are now built by several firms in sizes equivalent to their standard steam engines, and operate satisfactorily with various types of motors. Gas engines have found a very limited application to hoisting, but small gasoline hoists can be bought.

Signals are given the engineer by a "bell" in the engine house. It consists of a small whistle or a hammer striking a triangle, and is operated by a wire leading to a bell-crank on top of the shaft, thence to the bottom. A coil of wire is usually clamped to the horizontal arm of the bell-crank and paid out as the shaft deepens. The weight of the wire in the shaft is counterbalanced by weights hung on a third arm of the bell-crank or otherwise arranged. No. 6 galvanized-iron wire is good for a 500-ft. shaft; for greater depth ¼-in. strand is better. The bell-crank may be conveniently placed in the head-man's shanty.

Regular stopping places for the bucket, such as the "steady," are marked by the engineer by tying cotton cord around the rope. It is to enable him to see these marks more readily that the lever stand should be placed behind the engine.

After a shaft has reached a depth of about 200 ft., it becomes necessary to steady the bucket very carefully

before hoisting, to prevent its striking the timber. With a common rope the bucket also rotates rapidly on a long hoist. To avoid these effects, guides and a "billy," or "dummy," Fig 4, are installed. The billy is a light frame of wood or iron composed of two upright parts engaging the guides, and a cross-bar, through the middle of which the rope passes. It is carried by a buffer, clamped to the rope 4 or 5 ft. above the chain socket. The guides usually are terminated at the bottom of the last placed section of permanent lining, and buffer blocks stop the billy at this point, the rope running through the hole in the cross-piece as the bucket descends into the bottom. If the billy is made of wood, this hole should be lined with iron to prevent cutting. Old rubber pump valves make good buffers on the rope and on the stop-blocks.

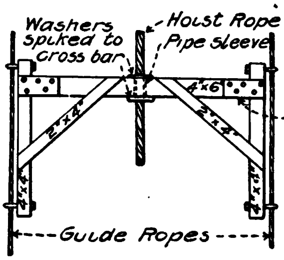


FIG. 4. — "Billy"

Both wooden and wire-rope guides are used for the billy, but even where the permanent guide timbers are available, rope is to be preferred. It can not only be placed more quickly and cheaply than timber, but it is safer. With timber there is a likelihood of the billy sticking, and then jarring loose and falling on the bucket; with wire rope this danger is avoided. At a shaft in Western Pennsylvania several years ago, the billy, after sticking on some ice on the wooden guides, fell and killed four men.

The use of a billy prevents any rotation of the bucket above the bottom of the guides, but below them the rotation seems intensified. To obviate this difficulty, non-rotating ropes have been devised. One form consists of a core and two layers of 7-wire strands wound right-handed and left-handed, respectively. The wires in the strands may be wound either common or lang-lay. These ropes fulfil their purpose (in fact are specified in some recent contracts), but

do not wear particularly well. It is impossible to use an ordinary lang-lay rope for sinking as it will entirely untwist.

Secondary-power Producers. — The most important of the secondary-power producers around the sinking plant is the air compressor. As yet, electricity has been unable to compete with steam or compressed air as a motive power for rock drills or sinking pumps; for underground work air has incidental advantages over electricity in that it assists ventilation and cannot ignite explosive gases.

The simple straight-line air compressor is the favorite for sinking. It is made by a number of firms; the Ingersoll-Rand Co.'s sizes range from 10-in. steam $\times$ 10¼-in. air $\times$ 12-in. stroke to 24-in. steam $\times$ 24¼-in. air $\times$ 30-in. stroke, with capacities of 177 and 1223 cu. ft. of free air per minute, respectively. It is more efficient mechanically than most small engines, and is wonderfully dependable with reasonable care. The 16 $\times$ 16¼ $\times$ 18-in. size is a convenient one for a pair of shafts; it has a capacity of 500 cu. ft. and will readily operate four drills and a small pump.

A straight-line compressor with a two-stage air end, Fig. 1, is made, which, according to the statements of the manufacturers, ought to be a good investment. With a steam consumption of 45 lbs. per indicated horse-power at half cut-off, the simple compressor has, for each indicated horse-power, a capacity of 5 cu. ft. of free air per minute compressed to 100 lbs. With the same steam consumption the two-stage compressor will deliver 15 per cent. more air. For 500 cu. ft. free air per minute, the saving of the two-stage over the simple type will therefore amount to 15 per cent. $\times \frac{1}{5} \times$ 500 cu. ft. $\times$ 45 = 675 lbs. steam or 150 lbs. coal per hour. With the compressor operating to capacity twenty hours per day, six days a week, the saving in three months, with coal at $4.50 per ton, would thus be $525. This is somewhat more than the difference in cost of the two machines.

On tunnels and similar work, where a number of shafts and headings are to be driven along a line, it is economical

to put up a central power plant at a point where coal can be most conveniently delivered and to pipe the air to the several openings. For installations of this kind, the cross-compound condensing steam, two-stage air compressor is best. A good-sized machine of this type, fitted with Corliss valves and a well-designed inter-cooler, has a steam consumption of 16 to 18 lbs. per indicated horse-power hour, and will compress 5.8 cu. ft. of air per minute per indicated horse-power. All the figures given for air-compressor power apply to 100 lbs. receiver pressure, the machines operating at sea level.

When the air is piped to a considerable distance, an after-cooler at the compressor will condense a large proportion of the water vapor carried, and thus prevent the formation of ice in the pipes and valve chests. Freezing is also prevented by the use of a reheater in the pipe where the air is to be used, which also increases the power obtainable from cold compressed air at a small expenditure of fuel. A good reheater will receive air at 60° and deliver it at 240°, thus raising the volume and the available power 25 per cent. with an insignificant coal consumption, if the air can be used before it cools.

Electric light is now essential for effective night work anywhere, and is particularly useful at a sinking shaft where the outside work must be carried on under all conditions of wind and weather, and the inside work sometimes under conditions (such as great quantities of falling water and explosive gases) that make the maintenance of an open flame impossible. Very little power is needed, as two arc lights and 30 incandescents will give abundant illumination in and around any single shaft. A 5-kilowatt generator is thus large enough to light a pair of shafts, but as it may be desirable to supply light to other work near the shafts, or to run one or two small motors, it is better to double this size. Small direct-connected units are made that are compact and easily handled but are expensive; and the care that machinery gets around construction work does not

warrant the use of a small and delicate high-speed engine. A cheap and satisfactory light plant is formed by an 11¼ kilowatt generator, belt-connected to an 8 × 12 in., horizontal, medium-speed, automatic engine. The voltage

FIG. 5. — Sinking Head-frame showing Dumping Arrangement

should not be higher than 220; even 110 will give quite a severe shock to a man who is soaking wet.

The outside wiring calls for no especial comment. In the shaft, however, very thorough insulation is required on account of the constant fall of water. In sinking, the bottom lights must be raised before every shot, and it is

most convenient to suspend them by their own wire from a reel. The reel may be kept on top of the shaft for 400 or 500 ft. of sinking, and then moved down to reduce the weight of hanging wire. A suitable reel may be cheaply built of wood by a carpenter. The two wires should wind on separate drums on the same shaft, so that they will hang entirely clear of each other. If a wooden shaft is used, the journals may be covered with copper strips, and made to serve as collecting rings.

Six 16 candle-power bulbs arranged as a cluster will light the shaft bottom. They should be set in waterproof sockets and protected against breakage by wire screens. An inverted dishpan hung above the cluster, with the wires passing through a hole in the middle, will shed falling water, and also act as a reflector. The wires must be heavily insulated where they pass through the pan.

Of the auxiliary mechanisms of a sinking plant, machine tools and small fans or blowers may be advantageously motor driven. If a large fan is necessary, it is simpler and safer to drive it direct by a separate engine. A very useful machine, that may be either engine or motor driven, is a swinging cut-off saw for cutting lagging to length. Such a machine will pay for itself on a single deep shaft.

Buildings. — After the machinery has been selected and set up, it is necessary to house it and the men that operate it. The cheap and obvious building materials for temporary work are 1-in. boards and tar paper. They are also highly inflammable, and on that account should be used with discretion when it comes to covering valuable machinery. It is surprising how completely the burning of a board shanty will wreck an engine inside it. Twenty-two gage corrugated iron can be bought and erected nearly as cheaply as boards and paper, and should at least be used for covering the compressors and engines. In cold weather it is hard to heat a corrugated iron building, hence boards are preferable for shifting shanties, etc.

The buildings needed around a sinking shaft are: Boiler

house; compressor and dynamo house; engine house; shift shanty; blacksmith and machine shop; powder house; oil house; powder thawing house; office and tool house.

The sizes and styles of these depend on the size of the job and the desires of the man who is running it. He may consolidate or omit some of them. In general, however, they all have different functions and should be separate.

If the boilers are under the same roof as the machinery, they should be divided from it by a tight partition to keep cinders and dirt out of the bearings. The shift shanty should be adjacent to the shaft, large enough for all the men

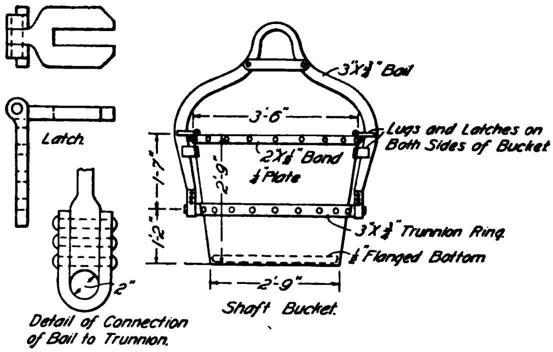


FIG. 6. — Details of Sinking Bucket

on the shift to change their clothes at once, and should have plenty of pegs for drying clothes, and a good stove or radiator.

The powder house and the oil house should be separated from each other and the former placed some distance from the job. They should be only large enough to contain the stocks of dynamite and oil actually needed, and should be built of iron to lessen the risk of fire and lighting. Caps and exploders should never be stored with dynamite. The powder thawing house is preferably a box or closet that will hold three or four boxes of dynamite, and is heated by steam coils. It should be so constructed that loose sticks of powder cannot come in contact with the hot pipes. Thawing boxes covered with manure are sometimes used, but are not safe, as manure is liable to spontaneous combustion.

The blacksmith and machine shop should contain a forge fitted with bellows or hand blower as well as a blast connection to the air line, benches with common and pipe vises, a grindstone, a small drill press, and, on a good-sized job, a pipe cutting and threading machine. The small tools should comprise blacksmith and drill-sharpening tools, pipe dies and cutters, bolt dies and taps, a ratchet drill, hacksaw, hammers, monkey and pipe wrenches, chain tongs, etc. A good assortment of miscellaneous pipe fittings and drill repairs should be kept on hand.

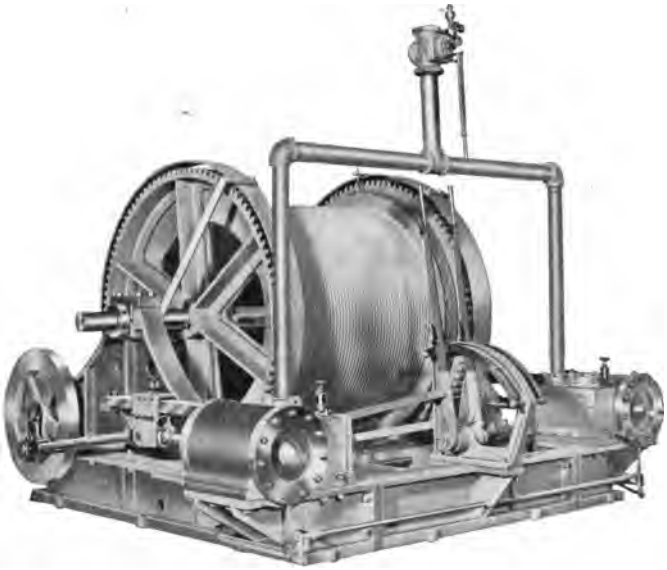


FIG. 7. — Double Spur Gear Reversible-link Motion Lidgerwood Hoist

The contents of the tool room also depend on the size of the job, but a good equipment saves money in the end. The following articles are either necessary or very useful: Good assortment of round and flat blacksmith iron, assorted nuts and washers, packing for engine and compressor glands and pumps, gasket, waste, oil cans, torches, crosscut saw, crowbars, striking hammers, picks and shovels, assorted nails, manila rope and blocks, cant hooks, lever jacks, etc.

The general layout of the job depends so largely on local

recommendations. The location of the boilers has already been discussed; if a railroad siding leads to the shaft, it is well to place the line of boilers parallel to it, so that coal can be unloaded directly into bunkers. The storage and subsequent handling of timber must also be considered. The temporary buildings should be so located that they will not be put into a hole by the encroachment of the dump; the position of the dump itself must be considered with relation to the drainage of the surrounding ground. The sinking engine, boilers, and machinery (as is usually specified) should not interfere with the erection of the permanent mining plant. Lastly, it may be again stated that too much attention cannot be given to the piping system all over the job as regards tightness, drainage, and insulation.

Cost. — The cost of a plant for a single shaft, assuming a depth of about 500 ft. and a moderate inflow of water, say 30 or 40 gallons a minute, is as follows:

Sinking engine	$1,000
Two 80 horse-power boilers and setting	1,800
Pipe and auxiliaries	500
150 horse-power heater	300
14-inch compressor	1,750
Three drills and steel	1,000
Shaft bar and clamps	100
Derrick	400
Head-frame	500
Two buckets	150
Rope	150
Buildings	500
Dump cars and rail	300
Electric plant, 10 kilowatts	750
Two pumps	500
Small tools	500
Total	$10,200

These figures are based on the cost of new machinery, and are large enough to include the necessary accessories. The cost of erecting and dismantling such a plant will be from $1000 to $2000, depending on location, labor conditions, etc.

CHAPTER III

SINKING THROUGH SURFACE — SOFT GROUND — WOODEN SHEETING — STEEL SHEETING — CAISSONS OF STEEL, WOOD, OR CONCRETE.

SINKING THROUGH SURFACE

IN most localities a certain amount of soil or soft ground overlies the ledge rock. Its depth varies from nothing to hundreds or even a thousand feet, and its nature is as varied as that of the rocks which it covers. The shaft sinker is interested chiefly in its consistency, which determines whether the penetration of the surface will be the easiest or the most arduous and expensive part of his job.

There is no hard and fast line of demarcation between firm ground and running ground; every degree of hardness or softness can be found from boulder clay to river silt, but ordinarily in sinking, ground is considered firm when the excavation can be carried ahead of the support, and soft when the support must be driven ahead of the excavation. In the first classification are included boulder clay, ordinary dry blue or yellow clay, cemented or clayey gravel and most loam soil; loose sand and gravel and silt come under the second.

The amount of water in the ground has a very great effect on its firmness, as is shown by the caving of excavations after a rain storm; conversely, soft wet ground may be made comparatively firm by removing the water. The commonest application of this principle is the use of compressed air for driving quicksand tunnels without the use of a shield. In this case the water is forced back away from the face into the surrounding ground, and timbering opera-

tions can be performed readily, which would be utterly impossible if the water were allowed to flow into the bore of the tunnel.

A trench in quicksand was recently driven at Gary, Ind., with very great success; here the water was drained in advance of the excavation through a number of small perforated pipes driven into the ground and connected at the

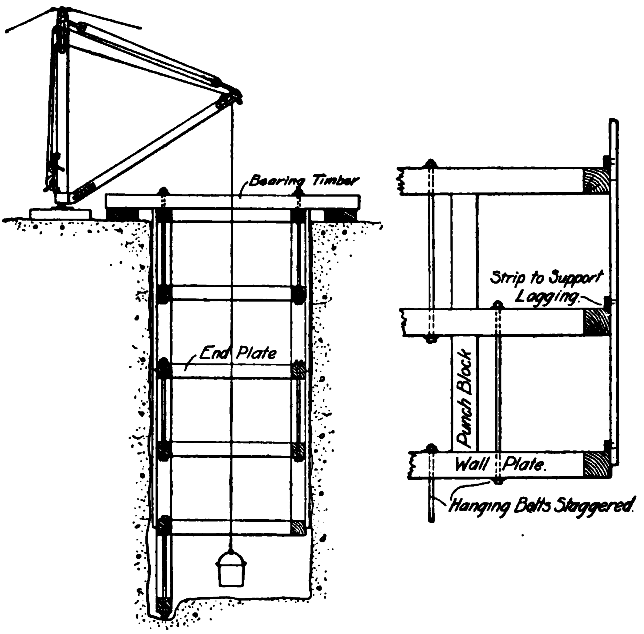


Fig. 8. — Hanging Timbers in Firm Earth

upper ends to the suction side of a pump. The writer knows of no case in which quicksand has been drained in advance of the excavation of a sinking shaft by driving small suction pipes into it, but in view of the success of the plan in the trench instanced above, he sees no reason why it could not be worked out for a shaft.

Compressed air is extensively used for sinking bridge piers and other caissons through soft ground; the application of this process to shafts will be considered later.

Concrete masonry is now almost entirely used for permanently supporting the sides of shafts in soft ground.

The methods in use for temporary support while sinking are:

Timbering; this heading includes the driving of wooden or steel sheet piling, as well as forepoling.

Caissons; these may be open drums, or closed drums sunk under compressed air.

Iron sinking drums and shoes, forced down hydraulically.

The freezing process.

The first method is applicable to comparatively easy surface conditions; the others to more difficult conditions. The last two have been developed in Europe for sinking through great depths of sand or mud, and are not extensively used in this country. The various methods will be treated in order.

Timbering — While sinking through ordinary surface ground the sides of the shaft are usually supported by square-framed horizontal sets of timbers with vertical lagging behind them. The distance between the sets depends upon the firmness of the ground, and varies from about 6 ft. as a maximum to nothing for "skin to skin" timbers in soft material. In square-framed sets the end and side pieces are termed "end plates" and "wall plates," respectively; the cross-struts, "buntons," and the posts which separate the sets, "punch blocks."

FIRM GROUND

The cheapest kind of sinking is afforded by earth that does not require blasting, yet is stiff enough to stand vertically for 4 or 5 ft. without support. In such material the usual procedure is to commence the excavation just large enough to admit the timber and lagging, and to carry the sides down vertically without support as far as it is safe to do so. The timbering is then started on the bottom and brought up to the surface of the ground. Two or more heavy bearing timbers, long enough to extend 4 or 5 ft.

beyond the lagging at each end, are laid across the shaft on the surface and their ends are supported by blocking them solidly against the ground, Fig. 8. The sets of timber are then hung from these bearing timbers by heavy rods, and sinking is resumed. As soon as 4 or 5 ft. of ground is removed, another set is placed on the bottom, hung with rods to the set above, and the lagging is worked in back of them in pieces just long enough to bear on both sets. The process is then repeated. Bearing timbers are usually placed over the end plates and over each row of buntons, and punch blocks are set at the corners and under the ends of all buntons. 10 × 12 in. timber sets, spaced 4 ft. center to center and braced so that the longest span will not exceed 12 ft., will safely support firm earth for a depth of 60 or 70 ft. The weight of the timbers is partly carried by the friction of the earth against the lagging, and the hanging bolts are not subjected to great stress; they may sometimes be entirely omitted. A ledge of earth is in this case left under the bottom set, and the middle of the shaft excavated; inclined posts are then wedged between the shaft bottom and the timbers and the ledge removed. It is generally safer to use $1\frac{1}{8}$ or $1\frac{1}{4}$-in. hanging bolts, however. Excavations of this character can be done for a total labor cost, including the placing of timber, of $1.50 to $2 per cubic yard. As the softness of the ground increases, the distance between sets is decreased. Sometimes the lagging is omitted and the lower set worked in immediately under the one above. The consideration of this plan properly belongs under soft-ground work.

SOFT GROUND

Wooden Sheeting. — When ground is so soft that it will not stand vertically at all, it becomes necessary to support it in advance of the excavation. The commonest method of doing this in any kind of pit is to enclose the area to be dug out with a coffer of sheet piling, driven by hand or power, Fig. 9, and to brace the inside of the coffer as the

material is removed. In starting a shaft, two sets of timber, one 5 ft. or so above the other, are set up as a guide frame, and the sheeting driven around them. The top soil is usually firm enough to enable these sets to be placed below the surface, but this is not, of course, essential. If the sets are placed above the surface, outside waling pieces are bolted through the sheeting at the top set in order to hold the top of the sheeting in line.

FIG. 9. — Successive Courses of Sheeting

In dry sand or other loose ground that does not contain much water, the sheeting is driven as the excavation progresses, and the points of the piles are kept only slightly below the bottom. Two-inch planks in 12 to 16 ft. lengths are commonly used in this case and are driven by hand with heavy wooden mauls. The heads should have beveled edges to prevent splitting, Fig. 10, and for hard driving, or with soft wood, a plate-iron cap may be used to advantage. By thus protecting their heads, the planks can be driven to their full length; a second course of sheeting is then driven inside the timbering of the first course, and so on until the required depth is reached. The economical limit for this

method, however, is about 50 ft., as it necessitates starting the shaft much larger than the minimum required size; some additional allowance must be made on every course for possible distortion and for inward bending of the sheeting at the points. Let us assume 50 ft. of surface, 10 × 10 in. timber, and 2-in. lagging, and a shaft 12 × 24 ft. with a 4-ft. concrete curb wall. Four courses of sheeting will be required, the last 20 ft. 4 in. × 32 ft. 4 in. outside, its wall plates to be buried in the concrete. Allowing 6 in. all around each time for distortion or squeezing, the third set will be 23 ft. 4 in. × 35 ft. 4 in., the second 26 ft. 4 in. ×

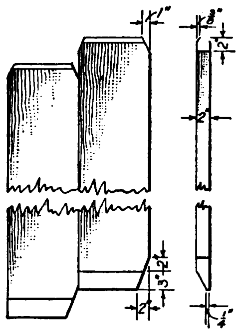


FIG. 10

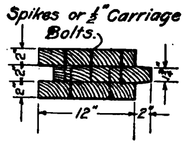


FIG. 11

38 ft. 4 in., and the first 29 ft. 4 in. × 41 ft. 4 in. The total excavation will thus be 40 per cent. in excess of that theoretically required for the curb wall. Any additional depth necessitating another course of sheeting will increase the percentage of useless excavation, and will require a larger quantity of heavy timber.

When many light sheet piles are to be driven, the work can be done more cheaply with some form of power driver than with mauls. A driver like an enlarged rock drill, Fig. 12, has been devised for this purpose, and a common drill fitted with a hammer instead of a bit will drive light sheeting satisfactorily. Either machine is suspended with blocks and falls from a trolley or tripod over the line of sheeting.

Steel Sheeting. — In quicksand or other wet running ground, sheeting must have joints that are almost water-tight, and as it is impossible to drive common plank close enough to make a satisfactory coffer in such material without caulking, some form of interlocking piling should be used. Formerly tongued and grooved, splined, or Wakefield piling, Fig. 11, were the only forms available, but now they

Fig. 12. — Sheet-pile Driver

have been superseded for difficult work by the interlocking steel sheet pile. A slight obstruction will cause wooden piling to separate at the bottom, whereas it is almost impossible to pull the steel piles apart. Steel piles, moreover, can be more easily driven, will penetrate most obstructions, and can be readily pulled and redriven. There are a dozen types on the market, each with its advocates, but the simplest shapes are those rolled by the Carnegie Steel Co., (*a*) Fig. 13, and by the Lackawanna Steel Co., (*b*) Fig. 13.

Both are strong and satisfactory and, though not watertight when first driven, will soon become so in most ground.

An additional advantage that steel piles possess is that they can be obtained in lengths up to 60 ft. and can be completely driven before excavation is started. When the ground is very bad, they should be made to reach rock so as to prevent material from flowing under their points. In one case a hole 36 × 27 ft. 6 in. in plan and 27 ft. deep was needed for a furnace pit; the material was soft quicksand and rock lay at an unknown depth. Steel sheet piling 48 ft. long was obtained and successfully driven entirely around the pit and followed down 4 ft. below the surface. The first 20 ft. of sand was easily removed, but as the depth increased, sand began to flow in under the piling and gradually bent their points inward, throwing a terrific strain on the lowest set of timber. A complete wreck was finally prevented by filling the hole with sacks of concrete which sank into the sand and supported the lower end of the piling. This enabled the desired depth to be reached, but it would have been practically impossible to reach rock if the hole had been intended for a shaft.

Steel piles and heavy wooden sheet piles must, of course, be driven by machinery. While a discussion of pile driving would be out of place in an article on shafts, it may be said that, in the writer's opinion, a steam hammer is preferable to a drop hammer for sheet piling, whether used in regular or suspended leads. Sometimes a water jet is necessary; with a jet piles can be easily sunk by the weight of the hammer through sands into which they cannot be driven at all.

The chief trouble in driving a steel-pile coffer is in making a good closure. Sometimes the last pile exactly fills the gap, but more often a lap joint is made which is caulked with hay or junk. With care a good joint can be made in this way. Steel piling in short lengths is used for cutting off thin strata of quicksand encountered some distance below the surface. In this case the piles are locked together all

the way around and each is driven only 2 or 3 ft. at a time until all reach the rock.

Steel piling can be driven through logs, strata of cemented gravel, etc., but in ground containing large hard boulders some other method must be used. At a quicksand shaft in Michigan, boulders were encountered, but steel piles were driven until they had apparently reached the desired depth. The coffer, however, could not be excavated, as the sand in some way flowed in as fast as it was removed. Compressed air was finally applied, and when the points of the piles were reached, they were found to be torn apart by the boulders. Several piles, bent through a full half circle, were pointing up the shaft.

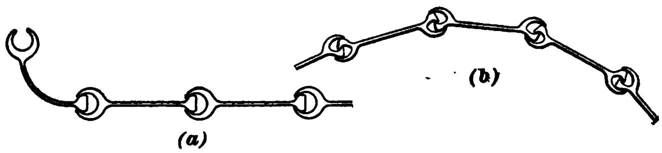


FIG. 13. — Sheet Steel Piling

Forepoling. — Forepoling was formerly used for shafts in soft ground of any nature, and depths of 100 ft. have been reached in the worst kind of material. Under such conditions forepoling is very slow and expensive, and although it has been largely, if not entirely, superseded by the steel sheet pile or caisson methods, some discussion of it is of interest. Forepoling is still widely used for soft-ground tunnels.

In starting a shaft which is to be forepoled through difficult ground, strong trusses are used for bearing timbers and the ring timbers are suspended from them by heavy bolts. The trusses span the shaft, Fig. 14, and their ends are supported by broad cribs or piers set well back from the edge of the shaft. They are built strong enough to carry the weight of all the surface timbering and also of the head-frame, if one is used. After the head-frame, or derrick, is ready, digging is started and the sides of the shaft are supported by short piles or poling boards driven on a

slant so that they bear against the outer face of the bottom set of timbers and the inner face of the one above. The poling boards are made twice as long as the distance between the sets (or longer), so when one course is driven home, enough ground can be dug out to enable another set of timbers to be placed. The worse the ground, the longer must the poling boards be made to prevent it flowing under them. The most troublesome places are the corners where the boards are divergent, and the spaces back of the buntons where a board is necessarily omitted. These openings are closed by short transverse boards placed as the excavation proceeds.

After a depth of about 40 ft. has been reached, the pressure of running ground becomes so great that single sets of timber, spaced so the poling boards can be driven between them, will not support it. Two or more timbers must then be placed "skin to skin" to form the wall and end plates, and as the depth increases the spacing of these compound sets must be reduced until the poling boards have to be driven nearly horizontal, and therefore fail to prevent the ground from rising in the shaft. This is where troubles with the forepoling method really begin. Every inrush of material causes a settlement of the ground around the shaft, throws the shaft itself out of line, and puts very great stresses on the timbers and the hanging bolts. In some cases heavy timbers driven with a ram have been used for poling boards. They were thus driven deep enough, and the successive courses were separated sufficiently, to permit very heavy ring timbers.

Among the other plans that have been devised to keep the bottom down may be mentioned:

Drainage of the ground ahead of the excavation by means of a perforated iron drum, jacked down and used as a sump for pump suctions. A short stoppage of the pumps will allow the ground to become saturated again and start a run, and besides it is very hard to keep pumps running steadily with sandy water.

Drainage of the ground by means of a timbered sump combined with a system of floor boards similar to the breast boards used in soft ground tunnels. This method is very slow and laborious.

Sinking quantities of hay and brush into the ground around the shaft by loading them with pig iron. This stiffens the ground to some extent and tends to prevent runs. It is a help with any style of timbering in quicksand, and may even be necessary in sinking a caisson.

Caissons. — In the last ten years many American engineers have adopted the sinking drum or open caisson for penetrating soft ground. A hollow cylinder of masonry is constructed on the surface with its axis vertical and its walls tapered outward at the bottom to a cutting edge. The outer surfaces of the walls should be smooth and vertical, and the cutting edge should be slightly larger than the rest of the cylinder. After the masonry has hardened the earth is excavated on the inside, and the caisson sinks of its own weight. It is kept plumb by digging out under the high side. When the top reaches ground level, another section is added and this continues until the cutting edge reaches rock. This method has long been employed in Germany, the caissons being constructed of brick or stone; in this country timber caissons have occasionally been used. The low tensile strength of brick or stone and the difficulty of sinking wood in bad ground made these materials unsatisfactory. Concrete, combining weight with strength, is almost ideal, and as it is not only better than timber and brick, but also cheaper, it has displaced them both for building caissons.

Rectangular Caissons. — Caissons are ordinarily circular, but sometimes are made rectangular of reinforced concrete. A noteworthy example of this type is a shaft recently sunk for the D., L. & W. R. R., on the flats opposite Wilkesbarre, Pa. This shaft, 48 ft. 10 in. × 14 ft. in the clear, was sunk through very wet quicksand to a depth of 70 ft., in four months, including the time lost in sealing the

caisson to the rock. It thus affords a decided contrast to the Pettibone shaft near by, which, sunk by forepoling, took eight years. Cost figures are unobtainable but seem unnecessary. The walls of the D., L. & W. caisson are 5 ft. 4 in. thick at the bottom, 2 ft. 8 in. at the top, and are plumb on the outside. Two reënforced cross-walls serve as buntons and also support the side walls.

Several rectangular caissons have been sunk along the Monongahela River in the flats above Brownsville, Pa. The ground is not very bad, but contains enough soft clay and quicksand to make timbering very difficult. Two of these were coal shafts and were sunk through 50 ft. of surface in two months in the winter of 1908–09.

Circular Caissons. — A circular caisson was sunk in the autumn of 1908 for Shaft No. 2 on the Rondout Siphon of the Catskill Aqueduct. The surface was about 60 ft. thick, of which 6 ft. was sandy loam. The balance was a wet material that resembled blue clay when dried out, but which in the ground was completely saturated. It flowed slowly like cold molasses, and was very sticky. Overlying the rock and entirely surrounded by the muck were quantities of hard boulders of all sizes, which had to be blasted from under the cutting edge of the caisson. The combination made as difficult ground to sink through as can well be conceived.

The shaft desired was a three-compartment shaft, 10 × 22 ft. outside the timbers, with two hoistways. The caisson was made 21 ft. inside diameter, Fig. 15, giving ample room for the hoistways and a ladderway; the area for air is of course in excess of that afforded by the rectangular shaft. This caisson was built and sunk to rock in two months, and a description of the method used for it will give a good idea of the process in general:

It was decided that a caisson with 30-in. walls would be strong enough and heavy enough to sink to rock, and a steel shoe or cutting edge 26 ft. in outside diameter was obtained. This shoe was formed of two ½ × 20 in. plates riveted

together at the bottom and flared at the top to include the lower part of the concrete wall. It was anchored to the concrete by about eighty ¾ in. × 8 ft. countersunk-head bolts.

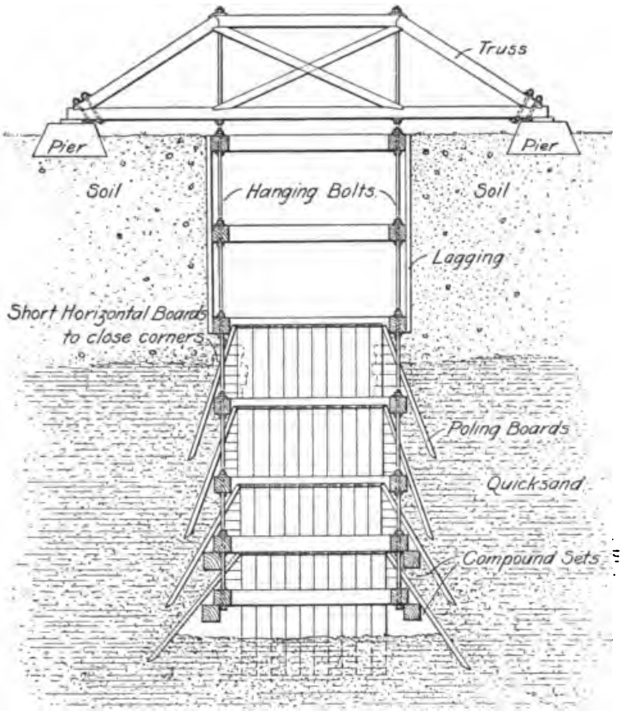


Fig. 14. — Forepoling

The shaft site was leveled, the shoe assembled upon short planks laid on the ground, and forms for the concrete were started. The forms were built of vertical 2-in. lagging in 4-ft. lengths, supported inside and out by rings of 4 × 3 in. angles tied together by ⅝-in. rods. Five feet of 1:2:5 concrete was placed and allowed to set for a week to obviate the possibility of settlement cracks above the cutting edge; 10 ft. more was then placed and, as soon as it had hardened sufficiently to permit of the forms being removed, sinking was commenced. The mud was loaded into shaft buckets

by men standing upon plank rafts and was hoisted with a derrick. Sometimes the mud had to be bailed with water buckets, but usually shovels could be used.

When the top of the first 15 ft. of concrete reached the ground level, 10 ft. more were added and excavation commenced again. Thus far the cutting edge had been very little in advance of the excavation, but at this point the caisson suddenly dropped 7 ft. and the mud inside rose 12 ft. The cutting edge was seen no more until it had almost reached rock. After the drop 20 ft. of concrete were added before excavation was started. Before this had been sunk to ground level, a stratum of very soft mud was encountered which ran in under the shoe and caused the surface to cave on the side next the derrick. The caisson gradually leaned toward the caving ground until it was nearly 2 ft. out of plumb. Sinking was then stopped, 10 ft. of concrete added, a trench dug through the 6 ft. of surface clay on the high side of the caisson, and the dirt banked against the caisson over the cave-in. When sinking was started the caisson began to right itself. It soon stopped moving, however, and the cutting edge was found to be resting on large boulders which had to be broken with dynamite. In the meantime the mud ran in almost as fast as it could be hoisted out, and the caving continued. When the cutting edge was within about 6 ft. of rock, the caisson literally stuck in the mud and refused to move even when the boulders were blasted out all around. A heavy timber platform was then built on top of the concrete and loaded with 200 tons of clay. As the caisson still stuck, the surrounding mud was agitated by blowing compressed air into it through 1¼-in. pipes which had previously been built into the wall; a 1½-in. pipe was also used as a jet and worked down to its full length on the outside. This was done over and over again all the way around. After a few hours the drum started to sink and reached rock without further trouble.

The trouble in this case was due to the great stickiness

of the mud. An additional thickness of 6 in. in the walls would have probably caused the caisson to sink without delay. As it was, only forty-eight days elapsed from the erection of the shoe to the commencement of rock excavation, an average progress of 1.2 ft. per day.

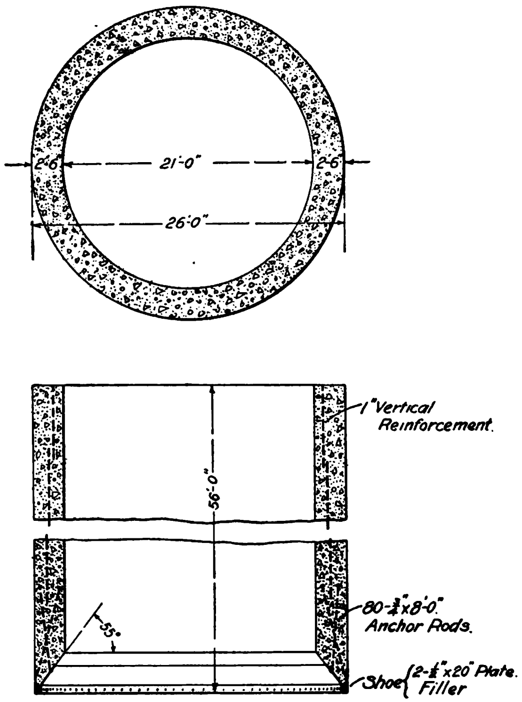


FIG. 15. — Circular Concrete Caisson

Fig. 16 shows the shoe and the lower part of the form, Fig. 17 shows the derrick, mixer, and general layout, and Fig. 18 shows the dump composed of mud spread out over an acre or more of ground.

All caissons should have some vertical rëenforcement, so that if the upper part sticks the lower part cannot drop away from it. The absence of this has caused several wrecks.

Steel shoes are only necessary in ground containing boulders. A concrete cutting edge properly reënforced is strong enough to penetrate sand or clay with safety.

A number of points must be considered in deciding whether to use a rectangular or a circular caisson in a given shaft. The circular shape is easier to build and sink, and, owing to arch action, thinner walls can be used. No horizontal reënforcement or cross-braces are needed, and therefore

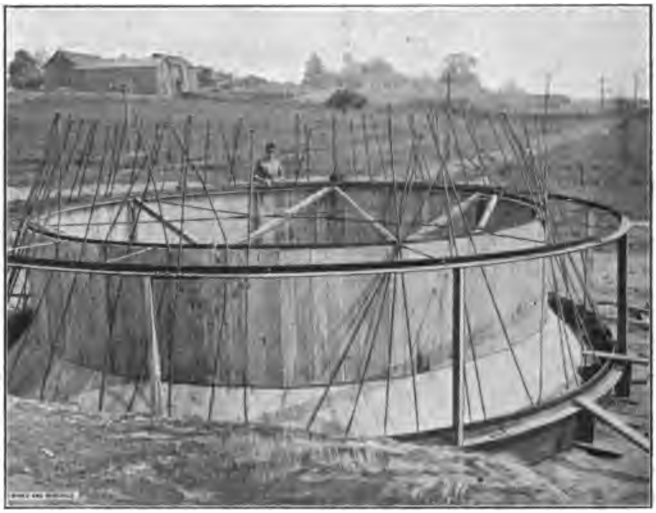


FIG. 16. — Shoe, Lower Part of Form, and Reinforcement, Rondout Caisson

a grab bucket can be used to advantage. The rectangular shape, on the other hand, requires less excavation, and the walls of any caisson must be made thicker than are needed for strength to give weight for sinking. In general it is probable that the circular shape is better for a one- or two-compartment shaft, and for a three-compartment shaft in very bad ground; the rectangular for a three-compartment shaft in ordinary soft ground. For long shafts, a rectangular caisson is a necessity.

An allowance should always be made for a possible tilt from the vertical that may amount to from 18 in. to 2 ft.,

either by battering or stepping the walls on the inside, or by making the caisson larger than the neat size required. In a rectangular caisson the side walls should be braced with temporary struts while sinking, and the permanent buntons or cross-walls placed after it has reached its final bearing on the rock; it may otherwise be impossible to line the guides up plumb.

The relative costs of piling, forepoling, and caisson are influenced by local conditions and by the type of shaft desired. For instance, a permanent shaft, such as the D., L. & W. shaft at Wilkesbarre, must have a masonry

FIG. 17. — Derrick and Head Works Rondout Caisson

lining through the surface anyhow, and it is therefore not fair to charge against the excavation the cost of the concrete in the caisson. In a temporary shaft, on the other hand, the excess of the cost of the caisson over the cost of a timber lining must be charged against the excavation. The writer believes, nevertheless, that wherever the ground is not firm enough to support itself for one set in advance of the timber lining, a caisson is safest and cheapest in the long run. A possible exception may be made to this statement in the case of a moderate depth of very wet ground where the work is done by a contractor who owns the equipment for driving steel piles and can recover them after the masonry lining is completed and use them on other work.

The costs given below should be fairly representative for the different methods of work:

1. Shaft excavated 14 × 20½ ft. through 6 ft. of soil and 14 ft. of quicksand, not very wet. Sides supported by 2-in. oak sheeting driven by mauls and braced by five sets of 10 × 12 in. timber.

FIG. 18. — Dump, Rondout Caisson, Showing Flowing Nature of Material

	Per Foot	Per Cubic Yard
Labor	$27.25	$2.57
Lumber, 6600 feet B. M. at $30	9.90	.93
Erection of derrick, etc.	3.00	.29
Superintendence	3.00	.29
Sundry	2.00	.18
Coal and pumping	5.00	.47
Total	$50.15	$4.73

2. Shaft excavated 12 × 20 ft. 3 in. through 45 ft. of clay and gravel. Sides supported by sets of 10 × 10 in. pine timber spaced 4½-ft. centers and hung from top. 1½-in. lagging:

	Per Foot	Per Cubic Yard
Labor	$19.50	$2.17
Lumber, 240 feet per foot at $25	6.00	.66
Bolts, 15 pounds per foot at $0.03	.45	.05
Erection of head-frame, etc.	2.00	.22
Superintendence	2.00	.22
Power	1.50	.17
Sundry	1.00	.11
Total	$32.45	$3.60

3. Shaft excavated 15 × 37 ft. through 21 ft. of dry sand. Sides supported by interlocking steel sheet piling driven with steam hammer and braced with sets of 8 × 10 in. timber:

Labor Costs Only	Per Foot	Per Cubic Yard
Driving sheeting	$ 6.55	$ .32
Removing sheeting	1.85	.09
Timbering	2.05	.10
Excavation	8.20	.40
Total	$18.65	$ .91

The cost of superintendence, sundries, and plant rental would amount to about $10 per ft. or .50 per yard at a low estimate, and the cost of the steel sheet piling, if charged entirely to this job, would amount to $110 per ft., or $5.30 per yard.

4. Caisson 26 ft. outside diameter, 21 ft. inside diameter, sunk through 56 ft. semi-liquid mud and boulders:

		Per Foot	Per Cubic Yard Excavation
Concrete	Materials	$ 27.00	$1.35
	Labor	7.00	.35
	Forms and shoe	23.00	1.15
Sinking caisson		38.00	1.90
Plant erection		3.00	.15
Superintendence		5.00	.25
Sundry		5.00	.25
Coal and power		6.00	.30
Total		$114.00	$5.70

SEALING THE CAISSON TO ROCK

After the cutting edge of a caisson has reached rock, it is still necessary to construct a seal to permanently exclude sand and water. Often a stratum of stiff clay or disintegrated shale is found under the soft material and immediately over the rock. If this occurs the cutting edge will sink into it, automatically shutting out water until a concrete wall is built; if not, the making of the seal will be very troublesome.

Running mud may be checked long enough to allow it to harden by caulking under the shoe with blocks of wood and old sacks. Streams of water and quicksand require a wedging curb of some kind. The English method of sealing tubbing to rock can be applied; this may be done, Fig. 19, by cutting out the rock under the shoe until the cutting edge attains a fair bearing all around, then driving numerous wooden wedges into the crack until the water is blocked back. Another plan, Fig. 20, is to lead the water to the center of the shaft through pipes set opposite the main

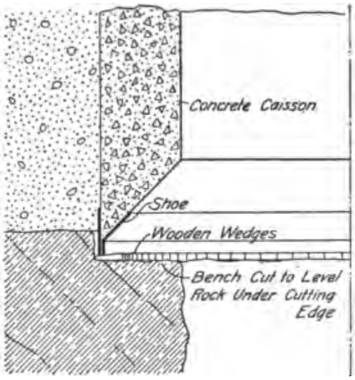


Fig. 19

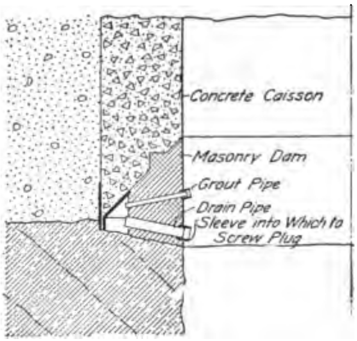


Fig. 20

feeders. A brick or concrete wall is then built from the rock to the caisson, surrounding the pipes and forcing all the water through them. When this masonry has set hard enough to stand the water pressure, the pipes are plugged. Several small pipes should also be built into the wall so that grout can be pumped back of it to take up small leaks. With either method great care is necessary, in commencing the rock excavation, to avoid opening up a new leak.

Sometimes the quantity of water may be so great that it cannot be shut off as described. If it is anticipated that the ground will be very wet, provision should be made in the design of the caisson for the use of compressed air as described below. This provision was made in the

FIG. 21. — Steel Shoe for D., L. & W. Caisson

FIG. 22. — Shoe and Form for Bottom of D., L. & W. Caisson

D., L. & W. caisson referred to above, although air was not used.

The following notes on D., L. & W. caisson, taken from the *Engineering News* for September 28, 1908, are of interest.

In sinking the shaft, after the surface had been removed with plows and scrapers and the bottom of the excavation

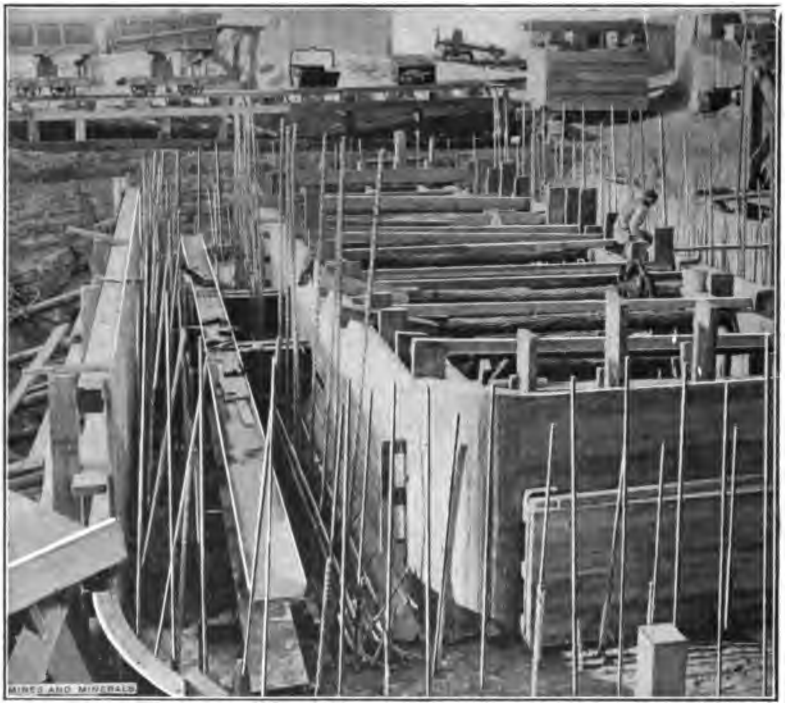


FIG. 23. — Showing Reënforcement for D., L. & W. Concrete Caisson

made perfectly level, a steel shoe, shown in Fig. 21, was placed on the bottom of the excavation. This was made of $\frac{3}{4}$-in. plate, was 24 in. wide, 32 in. high, and reënforced, as shown, with riveted angles. The shelf which formed the base for the concrete was placed 8 in. above the toe of the vertical plate. The outside dimensions of the cutting shoe were 28 × 59 ft. 5 in. The outside form for the concrete was built up flush with the outside edge of the shoe. The

inside form at the bottom was inclined as shown in Fig. 22, being given a batter until the wall was 7 ft. thick on the sides and 5 ft. on the ends, when vertical forms were put in place. The concrete was reënforced with tie-rods, as shown in Fig. 23, and the walls were decreased in thickness in steps, as shown in Fig. 25, until they reached a uniform thickness of 2 ft. 8 in. at the top. When a height of 20 ft. of the concrete was reached, the bottom forms were removed

FIG. 24. — D., L. & W. Caisson Ready for Sinking

and the concrete caisson then carefully leveled preparatory to sinking. In order to provide for the contingency of having to resort to compressed air in sinking in case the inflow of water proved too great to be handled by pumps, arrangements were made to put in an air deck in case of necessity. Sinking was carried on day and night, and the excavating gang consisted of a foreman and sixteen men to each shift. The materials were hoisted in buckets by means of derricks, as shown in Fig. 24. Just as the caisson reached the rock which was being cleaned off preparatory to putting in the seal, the river rose and the shaft was

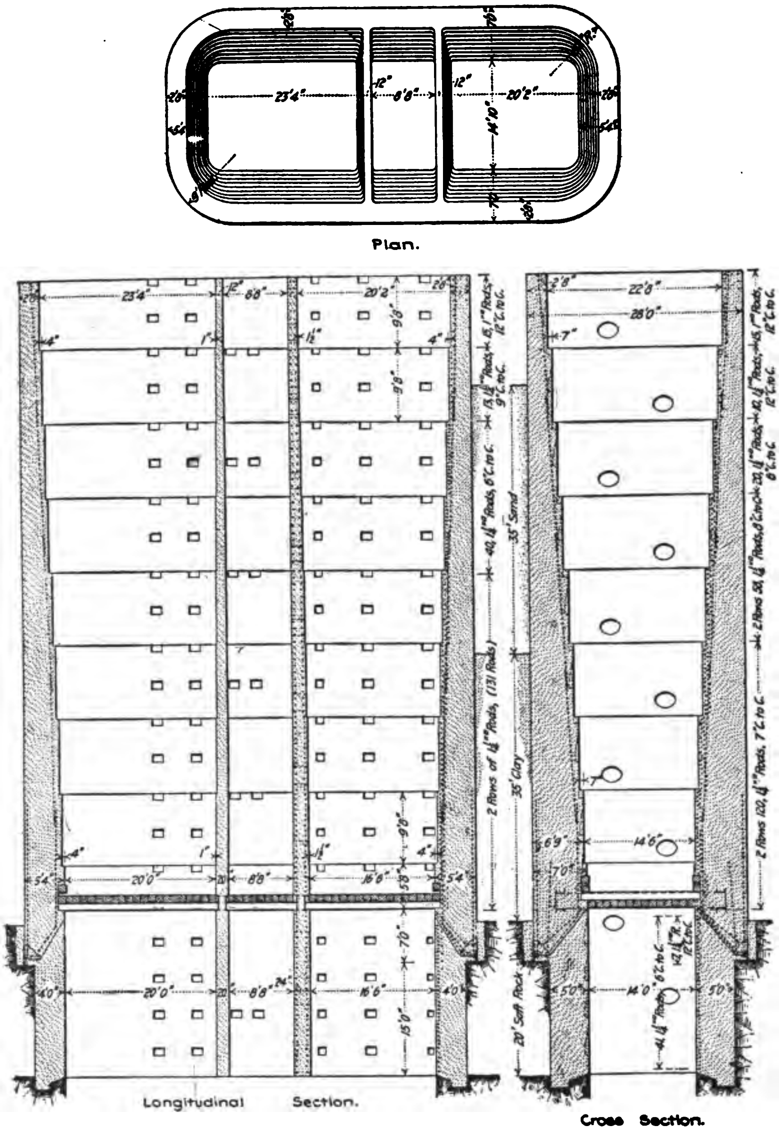


FIG. 25. — Plan and Sections of D., L. & W. Caisson Walls

flooded. It was found impossible to pump it out and the shaft was allowed to fill, to remain full until the river had subsided. When the caisson had sunk to the level of the rock, it was found that a temporary seal would have to be put in place during the construction of the permanent seal. This temporary seal was made of yellow pine blocks, 12 × 12 in. in size, and wedges *a*, Fig. 26. Six-inch bleeder pipes were left to drain off the water while the seal was being

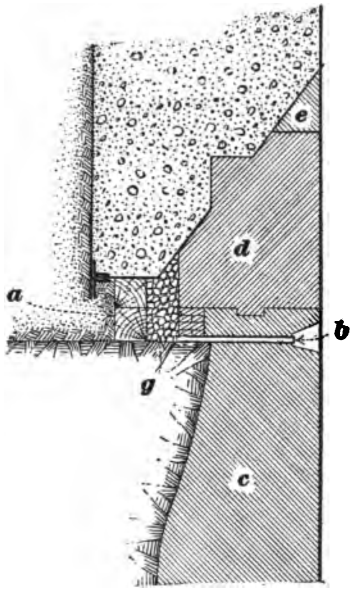


Fig. 26

put in place. The pipes were closed after the temporary seal had been completed.

To provide a place for the permanent seal it was necessary to take out rock for a depth of 20 ft., so as to build a wall to carry the caisson. During the blasting of this rock great care had to be taken to prevent jarring out the temporary seal. As the rock was being excavated a grout was forced back of the temporary blocking by means of a grout pump with an air pressure of 80 lbs.

In order to give a firm footing for the concrete wall the

rock was recessed so as to form a toe for the wall, and in order to give good contact between the underpinning wall and the caisson, the lower edge of the caisson was roughened. Fig. 26 shows the method of making the permanent seal between the caisson and the concrete foundation. The concrete *c* was put in place as soon as possible after the rock excavation had been completed, and was of the form shown. Next the ring of concrete *d* was placed, and grout was then pumped into the pipes after the concrete *c* and *d* had set. The final wedge of concrete *e* was laid after the concrete lower down had set and everything below had been made thoroughly tight, the edge between *e* and *d* being caulked after the pipe had been grouted; *g* is broken stone packed in between a brick dam and the wooden seal; the brick dam is intended to lead the water to the pipes *b*.

CHAPTER IV

Sinking through Soft Ground — Pneumatic Process — Shield Method.

SOFT GROUND

For sinking through soft ground containing more water than can be pumped, the three methods referred to in Chapter III have been developed in this country and abroad. They may be described as follows:

THE PNEUMATIC PROCESS

The pneumatic caisson is an application of the principle of the diving bell that has been widely used for founding deep piers. It is also used for soft-ground shafts, particularly construction shafts from which tunnels are to be driven under compressed air. A caisson is constructed similar to the open caissons already described, except that an air-tight deck is built over the entire opening 8 or 10 ft. above the cutting edge, Fig. 26. The deck is made strong enough to resist an air pressure equivalent to the hydrostatic head at the depth which the caisson is expected to reach. One or more openings in the deck are provided, fitted with air locks which retain air pressure but permit the entrance of men and the removal of spoil.

The caisson is constructed above the surface and sunk by excavating under the cutting edge as in the open type. The air pressure is raised as the caisson sinks and is always kept slightly in excess of the water pressure at the cutting edge. Water is absolutely excluded — no matter how wet and soft the material the work is done in the dry. In this way shafts can be sunk through river silt and flowing quicksands that cannot be handled in the open.

The cost of excavation under compressed air is in general much higher than that of open work. In the first place grab buckets cannot be hoisted through an air lock, so hand digging is necessary; second, a special class of high-priced laborers must be employed whose wages increase with the depth, while the length of the shifts must be reduced; third, the air locks applicable to caissons are costly to build, and as their construction is covered by patents controlled by one or two corporations, they are quite costly to rent; fourth, the masonry of the caissons must be made very heavy to overcome the upward pressure of the air. Some grounds, however, can be "blown" out of the caisson and very little digging is necessary; in this case excavation is cheap. The limit for pneumatic sinking in loose ground is, in general, 100 ft. below water level, as men cannot stand a pressure greater than that corresponding to this depth.

The deck in a shaft caisson must be removable, and is, therefore, made of timber or steel, fitted into a recess left in the wall. Two openings should be provided, one in the middle for the excavation lock and another for the man lock. American locks are now standardized to fit a 36-in. circular opening. Small openings must also be made in the deck for the air connections and the "blow pipe."

A man lock consists of a steel cylinder, about 4 ft. in diameter and 8 ft. long, with flanged head. Eighteen-inch openings in the head are fitted with doors which swing downwards in opening, and close against a rubber gasket. A small hole in each head, closed by a stop-cock inside the lock, permits the entrance of compressed air from the caisson and its escape to the atmosphere. The lower door and stop-cock being closed, the upper door is opened and several men enter the lock. The upper door is then closed from outside, and a lock-tender standing inside the lock closes the upper and opens the lower stop-cock. When the pressure in the lock has become equal to that in the caisson, he opens the lower door and the men climb down a

ladder to the bottom. In letting men out the process is reversed.

The locking through of men is the most precarious part of compressed-air work. Too quick an application of pressure causes "blocking of the ears" — intolerable pain in the ears and head due to unequal pressure on the two sides of the ear drum — and too quick a reduction of pressure

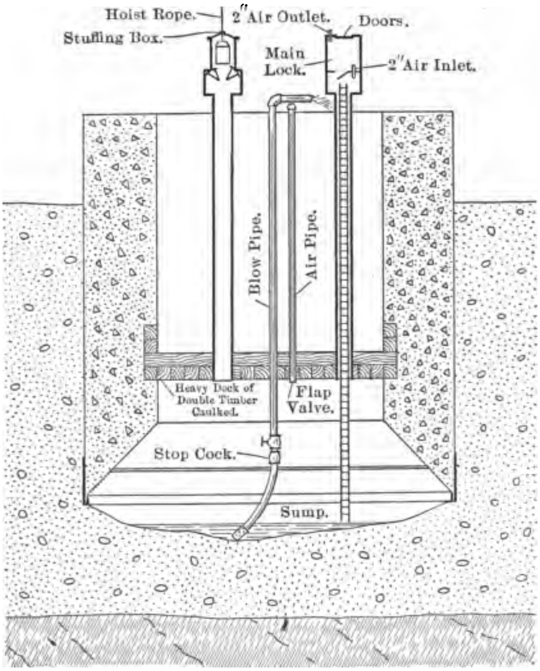


FIG. 27. — Pneumatic Caisson

may cause the "bends" — caisson workers' paralysis — always dangerous and sometimes fatal. For pressures below 20 lbs., men accustomed to the work can be locked through safely in two or three minutes and can work eight-hour shifts; at higher pressures the locking time must be increased and the length of the shifts decreased. With 45 lbs. of air, forty-five-minute shifts are worked and twenty-five minutes must be taken in locking through.

The principle of the excavation lock is the same as that of the man lock, but the doors and valves are all controlled from outside. The patented "straight-through" lock is the best type, in fact the only satisfactory type for caisson work. Several forms are made, all of which require the bucket to be hoisted on a single rope. In the "pot-lid" lock the rope passes through a stuffing-box in the middle of the upper door, which is literally a lid fastened to the lock by six heavy bolts hinged to the lock and engaging slots in the edge of the door. The door is carried by a buffer at the lower end of the rope. When a bucket is lowered into the lock, the upper door is also lowered on to its seat. The lock-tender, who stands outside, raises the hinge bolts into their slots and tightens the nuts before opening the lower door. In consequence of the continual tightening and loosening of the bolts this lock is rather slow in operation, but it is very simple.

Other forms of the straight-through lock have the upper door in two halves which close upon a stuffing-box on the rope. In this way only the stuffing-box is lifted instead of the entire door, and the operation is much quicker. In one type the doors are operated by high-pressure air cylinders.

The air pumped into the caisson by the compressors escapes by forcing its way out through the ground close under the cutting edge. As it is often necessary to excavate several feet below the cutting edge to sink the caisson, some provision must be made to remove the water that collects in the depression. This can of course be done with a pump driven by high-pressure air, but it is also possible to blow the water out directly. A 4 to 6 in. pipe, closed by a stop-cock at the lower end, is led through the deck and out over the top of the caisson, and a suction hose reaching the sump is attached to the lower side of the stop-cock. An opening, closed by a small valve or a wooden plug, is made in the pipe above the stop-cock. When the stop-cock is open the air pressure lifts the water into the pipe; the small

valve is opened at the same time and a quantity of air flows in and mixes with the stream of water, decreasing its specific gravity until the weight of the whole column of water is less than the air pressure. The water is then driven completely out of the caisson. By replacing the valve with a small high-pressure air connection it has been possible to raise water out of a caisson 70 ft. deep with 13 lbs. of air.

Fine sand and silt containing much water can be blown out through the pipe, and caissons have been sunk without hoisting a bucket of dirt.

The use of compressed air makes it very much easier to seal the caisson to rock. There is of course no trouble about keeping the water out; the difficulty is to prevent the air from blowing the grout out of the concrete, leaving it porous. One plan is to lay a strip of heavy duck over the crack, nailing one edge to the caisson and the other to the rock. Concrete is then laid on top of this duck.

Some kinds of very wet ground possess considerable viscosity. In these the pneumatic process can be worked to a greater depth than is theoretically possible by reducing the pressure and blowing out the mud and water that flow in under the cutting edge. One example of this has been cited — where water was raised 70 ft. with 13 lbs. of air; in England recently several piers were founded at a depth of 130 ft. below water level with 45 lbs. of air pressure. Under such conditions the difference between the hydrostatic pressure and the air pressure is accounted for by internal friction of the water and the ground. It is probable also that the actual hydrostatic head is reduced by the air bubbles which escape under the cutting edge into the surrounding ground.

THE SHIELD METHOD

Shields, similar in principle to those so extensively used for subaqueous soft-ground tunnels, have also been applied to soft-ground shafts, Fig. 28. A shoe is constructed with a cutting edge slightly larger than the outside of the com-

pleted shaft lining; a vertical lap plate or shield is attached to the outer perimeter of the shoe, and a number of screw (or hydraulic) jacks are set on top of the shoe and inside the shield plate. The frame of the shoe is sometimes made of wood, but steel is preferable. The shield is made of $\frac{1}{4}$ to $\frac{1}{2}$-in. plate iron and extends from 18 in. to 3 ft. above

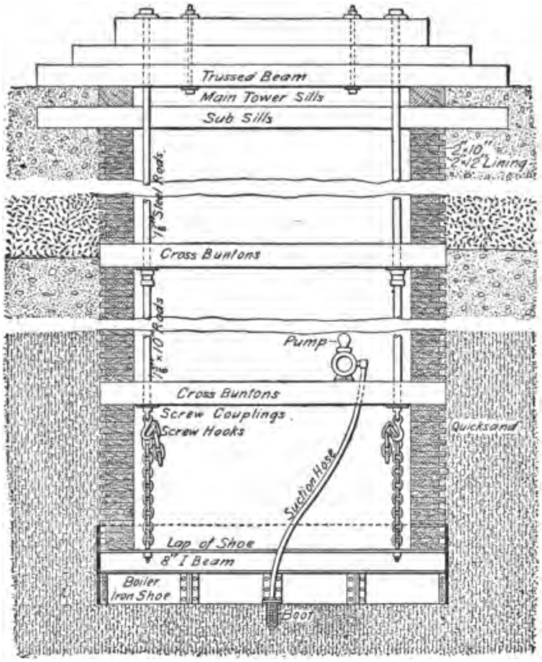


FIG. 28.* — Shield Method of Sinking

the top of the shoe proper. The method of operation is as follows:

As soon as the shaft is started, bearing timbers or trusses are constructed to hang the lining from as previously described in connection with forepoling. The shoe is assembled in place with jacks screwed down, and the shaft lining is completed from the surface to the heads of the

* Figs. 28, 34, 36, 37, and 47 are reproduced from the copyrighted instruction papers and bound volumes of the International Correspondence Schools by special permission of the International Textbook Company.

jacks. Excavation is then started and the shoe sinks until enough distance is gained to allow another course of lining to be placed beneath the completed section and inside the shield. If the jacks are used to force the shoe down, they must be withdrawn before the course of lining can be placed.

The upper edge of the shield must always be kept above the lower edge of the completed lining, and to insure this in bad ground it is necessary to hang the shoe from the bearing timbers with chains and ratchet jacks. Sometimes shoes are made so that the opening can be completely closed with steel plates to prevent an inrush of sand.

Tunnels driven with shields are circular and lined with rings of cast-iron segments 2 ft. wide. Many European shafts are lined this way, but the American shafts to which the shield method has been applied are rectangular and lined with "skin-to-skin" timbers or plank laid flat.

The chief disadvantage of a shield, even at a moderate depth, is its liability to hang up on a boulder on one side while the other side settles, thus wedging itself and throwing the shaft out of line. This tendency can be largely overcome by the proper suspension of the shield, but the depth which can be reached is limited when the ground is soft and wet enough to exert fluid pressure. At 100 ft. below ground-water level, for example, the pressure of wet quicksand will at least be 45 lbs. per square inch, sufficient to force enough sand and water to flood the shaft through a very small opening. It is impossible to jack a closed shoe down, displacing the ground under it.

CHAPTER V

Sinking in Rock — Arrangement of Holes — Tools and Methods Used in Drilling — Costs and Speed

Dynamite and the power drill have made solid rock the easiest material through which to sink a shaft, and practically all American mining shafts are in rock for the greater part of their depth. As has been said before, hand sinking is the cheapest and quickest method; although a boring process has been developed, it is only applied where such immense quantities of water are encountered that hand sinking is impossible.

Outside of the boring process, the improvements in rock sinking have all related to breaking the rock and hoisting it. No practicable mechanical excavator or loader has yet been devised. Grab buckets that work well in soft ground are failures in blasted rock. A steam shovel, useful in a tunnel, is of course out of the question in the bottom of a sinking shaft.

Drilling and Blasting. — The universal method of shaft sinking in rock is to drill a number of holes in the bottom, charge them with dynamite and shoot them, and to load the broken rock by hand into shaft buckets which are then hoisted out. When all the loose rock has been removed the process is repeated. As it is very difficult to drill holes through loose rock, the broken material must be all removed before the next round of holes is started. This creates an additional difficulty for the mechanical digger, for while a grab might be made to remove most of the loose rock after a blast, hand work would still have to be resorted to to get the bottom ready for drilling.

Shafts are drilled on the "center-cut" principle. Eight

or ten holes are drilled on a slant, separated at the top but converging, thus forming a wedge known as the "sump." "Reliever," or bench, holes are drilled back of the sump holes, each row being more nearly vertical; the end or outside holes point slightly away from the vertical and toward the wall line of the shaft. The sump is first shot and the broken rock removed or "mucked" out, forming a cavity into which the bench rounds can be successively shot. All muck should be removed before each succeeding round is shot.

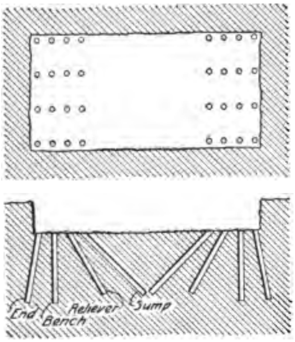


FIG. 29. — Shaft (*a*)

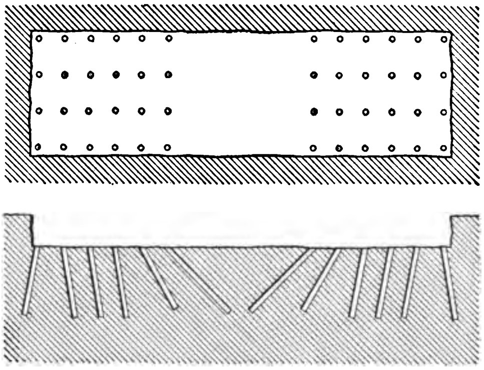


FIG. 30. — Shaft (*b*)

Two systems of drilling and mucking exist. In the first the holes for the entire cut — sump and benches — are drilled at one time, the sump is shot, and then the benches as required. In the second the sump only is drilled and shot, and the benches are drilled while the sump is being mucked. The first plan is particularly applicable to small shafts and to circular shafts; a rectangular or elliptical shape is needed to give room for simultaneous drilling and mucking.

Fumeless, or gelatine, dynamite should in all cases be used for underground work. The fumes from ordinary glycerine dynamite make it imposssible for the men to get back to work promptly after a shot. The strength of the dynamite used depends on the character of the rock, but

40 and 60 per cent. gelatine are the most common strengths used.

The number and depth of the holes and the quantities of powder loaded vary so greatly with the size of the shaft and the nature of the rock that no general rules can be stated. The systems actually used at several shafts were as follows:

(*a*) Shaft 13 × 26 ft., through Western Pennsylvania coal measures: Shale, slate, and limestone; horizontal stratification; holes as in Fig. 29; 40 per cent. gelatine:

	Number	Depth	Inclination with Vertical	Loaded with
		Feet	Degrees	Pounds
Sump	8	10	35	4
Relievers	8	8	25	3
Benches	8	8	0	2½
End	8	8	10 back	2½
Total charge	—	—	—	96

Average gain per cut, 6 feet.
Average gain per week of 19 shifts, 24 feet (no timber).
Mucking and drilling simultaneous; 2 drills used on 1 bar.

(*b*) Shaft 14 × 48 ft., through anthracite measures: Red sandstone; stratification horizontal; holes as in Fig. 30; 40 per cent. gelatine:

	Number	Depth	Inclination	Loaded with
		Feet	Degrees	Pounds
Sump	8	10	35	5
Relievers	8	8	25	4
Benches	24	8	10 to 0	3
End	8	8	10 back	3
Total charge per round	—	—	—	168

Average gain per cut, 6 feet.
Average gain per week of 18 shifts, 16 feet.
Mucking and drilling simultaneous; 2 drills used on 1 bar.

(*c*) Shaft 10 × 22 ft., through quartz conglomerate (Shawangunk grit); horizontal stratification, but very few bedding planes; holes as in Fig. 31; 60 per cent. gelatine:

	Number	Depth	Inclination	Loaded with
		Feet	Degre	Pounds
Sump	8	10	35	3½
Sump	4	8	0	3½
Relievers	8	9	25	2½
Benches	8	8	0	2
End	8	8	10 back	2
Total charge per round	—	—	—	94

Average gain per cut, 5½ feet.
Average gain per week of 20 shifts, 22 feet.
Mucking and drilling simultaneous; 5 drills used on 2 bars.

The four additional sump holes shown were used on account of extra hardness of the rock.

(*d*) Shaft elliptical, 19 ft. 4 in. × 33 ft., through West Virginia coal measures: Hard gray sandstone; 40 per cent. gelatine; holes as in Fig. 32; horizontal stratification:

	Number	Depth	Inclination	Loaded with
		Feet	Degrees	Pounds
Sump	10	12	35	5
Relievers	8	10	25	4
Benches	14	10	10	4
End	6	10	10 back	3
Total charge per round	—	—	—	156

Average gain per cut, 8 feet.
Average gain per week of 20 shifts, 18 feet.
Mucking and drilling simultaneous; 3 drills used on 1 long bar, 1 short bar.

(*e*) Shaft circular, 17 ft. diameter, through Hamilton and Marcellus shales: Rock distorted; stratification irregular; holes as in Fig. 33, but about 45 degrees; 60 per cent. gelatine:

	Number	Depth	Inclination	Loaded with
		Feet	Degrees	Pounds
Sump	6	8	35	2½
Relievers	8	6	20	1½
Rib	16	6	10 back	1
Total charge per round	—	—	—	43

Average gain per cut, 5½ feet.
Average gain per week of 19 shifts, 33 feet.
All drilling on one shift, mucking on two shifts; 5 drills used on 5 tripods.

Drilling Tools. — Hand drilling, once universal, has been entirely superseded in the United State by compressed-air drilling, and it is in fact difficult to obtain hammer men.

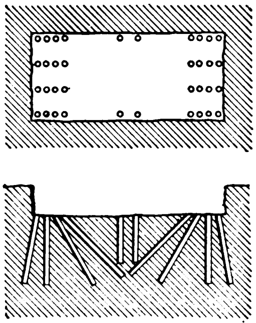


Fig. 31. — Shaft (c)

In other countries where labor is cheap, drilling is still done by hand. In the commonest method, a drill or "jumper"

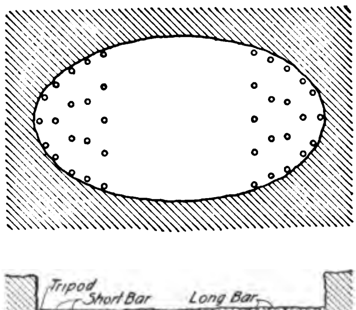


Fig. 32. — Shaft (d)

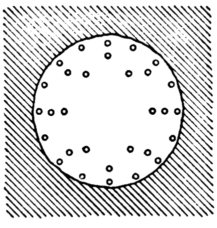


Fig. 33. — Shaft (e)

of 1-in. steel is turned by one man and struck by one or two others with 8-lb., double-faced hammers, Fig. 34*a*. Americans and Europeans use a 30-in. stiff handle; the Southern negro prefers to "drive steel" with a slightly longer

handle whittled down until it bends like a whip. Jumpers are given a single cutting edge, usually curved, Fig. 40. Two men should strike each steel wherever practicable, as they can obviously drill twice as fast as a single striker at three-fourths the cost. As much depends on the man that turns the steel as on the striker, for considerable skill is needed to produce a round, straight hole. Three good men can drill 1¼-in. holes in hard sandstone at the rate of 2 ft. per hour.

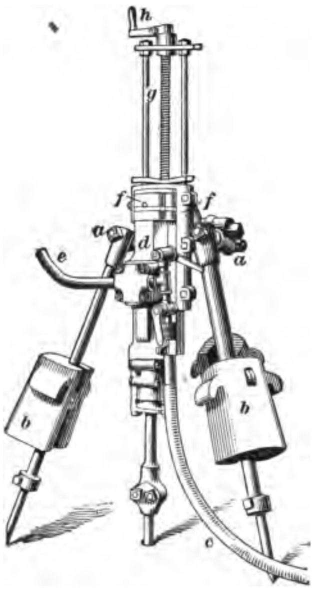


FIG. 34

FIG. 34a

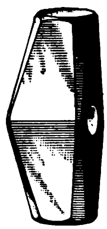


FIG. 34b

In the Tyrol a system of single-handed drilling has been developed. The driller turns a light steel with one hand and wields a 4-lb. hammer, Fig. 34*b*, with the other. A skilful man can thus drill 3-ft. holes quite rapidly, but the holes are too small for regular shaft sinking.

For slate, churn drills, Fig. 38, are often used. The drill consists of a straight bar, 6 to 12 ft. long, with a bit at each end. An iron weight is sometimes welded around or forged into the drill 2 ft. from one end, thus increasing the weight

of the drill without increasing its length or diameter. The drill is handled by two or three men. When the weighted drill is used, the hole is started with the short end, and when it has reached a depth of 2 ft. the drill is reversed.

Fig. 35

The reciprocating, compressed air drill is the most widely used machine for drilling rock. It was first put into practical use by Mr. Fowle, of Boston, in the construction of the Hoosac tunnel, and since then has steadily grown in popularity. It is turned out by the thousands by the

Ingersoll-Rand Co., the Sullivan Machinery Co., the McKiernan Drill Co., and others, and although each maker has certain features of his own, especially in the valve arrangement, the general design is standardized and the general features are shown in Fig. 36. Piston and rod are turned out of a single billet of special steel, and to the end of the rod the drill steel is rigidly attached by a U-bolt chuck. The cylinder is made of cast-iron and slides longitudinally in a guide frame (or shell) clamped to the drill mounting. As the drill cuts into the rock, the cylinder is fed forward by a square-thread screw mounted on the frame. The piston is rotated mechanically by a "rifle bar" and ratchet so that the cutting edge of the bit will not strike two successive blows in the same spot. This rotative effect is necessary to drill a round hole.

The machine commonly used for shaft sinking has a $3\frac{1}{4}$-in. cylinder and a $6\frac{1}{2}$-in. stroke, weighs 280 lbs., and will drill down holes in hard rock at the rate of about 7 ft. per hour, including time lost in changing steels. The length of feed is 24 in., hence the drills must be changed every 2 ft. The starter is 2 ft. long beyond the shank (the portion of the drill grasped by the chuck), and the following steels are 4 ft., 6 ft., 8 ft., etc., respectively. (See Fig. 39.) Drill steels are usually sharpened with a + bit, although **X** bits and straight **I** bits are sometimes used. Where a large number of drills are in operation a sharpening machine may be used to advantage.

Two types of valve motion can be obtained. In the first, the valve which controls the piston is thrown by a tappet struck by the piston itself; the Rand "Little Giant" is an example of this. In the second, a piston valve is used which is thrown by a difference in air pressure on the two ends. The Sullivan "Slugger" is a drill of this type. The Sergeant drill is a compromise, having an auxiliary valve, driven by contact with the piston, which governs the air pressure on the ends of the main piston valve. The Slugger type strikes a hard, uncushioned blow and is adapted to

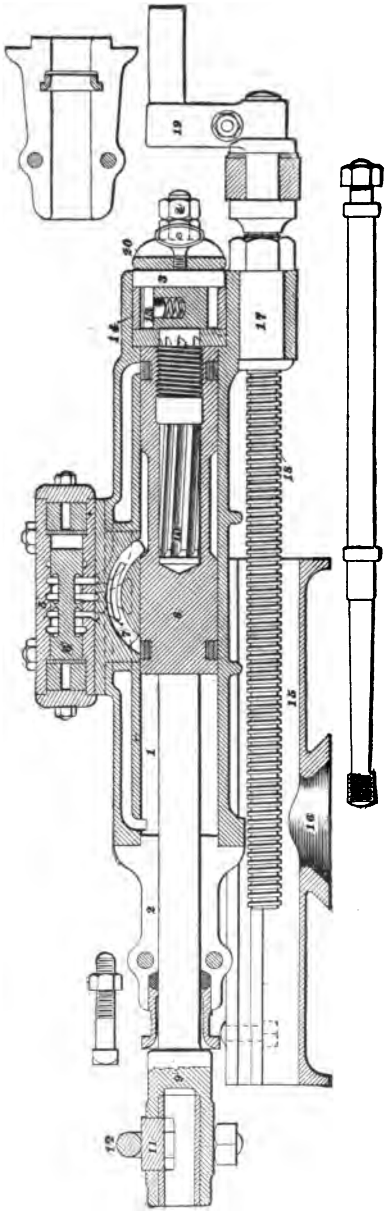


FIG. 36

use in hard rock with compressed air. Wet steam will not operate the valve readily, and the drill is slow if wet steam is used. The tappet drill, on the other hand, having a positive valve motion will do good work on wet steam. Its blow is slightly cushioned. The auxiliary-valve drill strikes a hard blow, will run by steam, and in addition has the advantage of a variable stroke. This feature makes it easier to start a hole.

A good many types of air-hammer drill have been recently developed, and have replaced the reciprocating types for light work. In these the drill steel is struck by a reciprocating hammer and has very little motion of its own. The drill steel is hollow, and the powdered rock is blown out of the hole by a portion of the exhaust air led to the cutting face through the hole in the steel. The Water Leyner drill, Fig. 35, which is now built to compete with the larger sizes of reciprocating drills, works on the hammer principle. In this the cuttings are removed by a stream of water pumped through the hollow steel to the cutting face; a portion of the exhaust air is allowed to mix with the water. This drill has made some remarkable records in hard rock tunnels in the West. A great advantage of the drill is that no dust is created in drilling up-holes in tunnels, making this work very much more healthy for the drill runners.

In rectangular shafts, drills are mounted on "shaft bars," or single screw columns, Fig. 37. The drill itself is held by a clamp, which, when its bolts are loosened, can be slid along or revolved around the bar, at the same time permitting the drill to be swung sidewise to any angle. When the clamp bolts are tightened the drill is rigidly held in position. The bar is set horizontally across the shaft, wooden blocking being used to form a good bearing between its ends and the walls of the shaft. Two and sometimes three drills are mounted on each bar. "Column arms," used for offsetting the drill, do not work satisfactorily with a shaft bar, and besides are unnecessary in a rectangular shaft.

In circular shafts it is difficult to cover the area to be drilled with a straight bar, and in the writer's opinion it is best to mount the drills on tripods, Fig. 34. The tripod, while it possesses all the adjustability of other forms of mounting, is less rigid and more cumbersome. To do good work all loose rock should be removed and the legs set on solid rock. This feature, however, is not objectionable in a shaft where mucking and drilling are not carried on simultaneously.

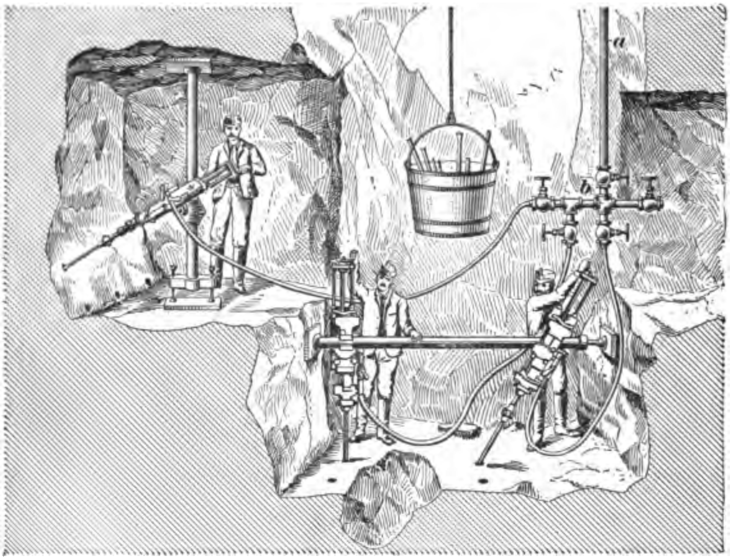


Fig. 37

Before blasting, the drills and mountings must of course be hoisted out of the shaft. In England, a drilling frame for use in circular shafts has been patented. This consists of a ring from which six bars, on which the drills are mounted, project radially. The ring is supported by legs and held rigid by jack-screws in the ends of the six bars. The chief advantage of this frame is that it is unnecessary to detach all the drills before blasting; the whole can be hoisted off the bottom and hung in the shaft without hindering the

Fig. 38

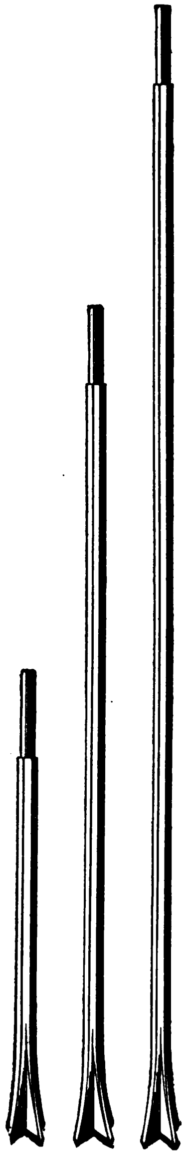


Fig. 39

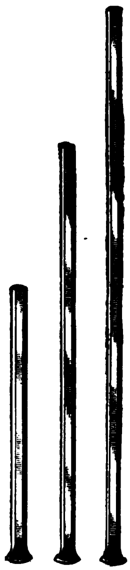


Fig. 40

passage of the bucket which passes up and down through the ring. Another advantage of the frame is that the manifold is attached to it, the drills being connected to the manifold by short pieces of hose. It is thus necessary to have only one main air hcse hanging in the shaft instead of a small hose for each machine.

The best grade of canvas and rubber hose should be used for the drills, wire wound for air, and marlin wound for steam. "Steam hose" should be ordered always for use with steam, as "air hose" will not stand heat. A section of 1-in. hose 50 ft. long is used for operating each drill.

Operation. — Shaft sinking is usually carried on twenty-four hours a day. The inside work is done by three shifts of men working eight hours each, the outside by three 8-hour or two 12-hour shifts. The 12-hour outside shift is customary in the coal fields; elsewhere, the 8-hour shift for every one is prevalent. Shifts are usually changed at 7 A.M. and 3 and 11 P.M., sometimes an hour later. The men are given twenty minutes for lunch in the middle of each shift.

Wages vary with the locality, but in general men are paid better for drilling and mucking in a shaft than in any other kind of rock excavation. On account of the high wages paid in America machine drilling is universal, and the shifts are limited to the number of men that can be worked to the best advantage. Speed is not attempted at the expense of efficiency. In South Africa, on the other hand, Kaffir labor is cheap, hand drilling is usual, and as many men are worked as the shafts will hold.

The great depth of the shafts on the Rand makes the highest possible speed desirable, even at an increased cost. In both countries speed is increased without an increase of cost by the payment of a bonus to the sinkers as a reward for additional progress.

The size of the shifts for any given shaft depends upon the number of drills required and upon the experience and ability of the sinkers obtainable. With first-class men,

the men on each shift at the 13 × 26 ft. shaft referred to before as (*a*) would be as follows:

Inside men, 8 hours: One shift boss, at $3; two drillers, at $2.75; two helpers, at $2.50; six muckers, at $2.25.

Outside men, 12 hours: One engineer; one head tender; three car men on dump; one fireman; one compressor man.

General outside, 10 hours: One foreman; one mechanic; two carpenters (on timber); one blacksmith and helper.

The 17-ft. circular shaft (*e*) would require:

Drilling shift: One shift boss; five drillers; five helpers; one extra man.

Mucking shifts: One shift boss; nine muckers.

Outside same as shaft (*a*).

In South African shafts, which are usually about 9 × 26 ft., when drilling is done by hand, each shift consists of one white shift boss and about 35 Kaffir laborers who drill or muck as may be required.

Thorough organization is essential to progress and economy. Each man must know his place and take it without losing time in getting started. Any condition that prevents systematic work is fatal to economy. For instance an inflow of water, sufficient to cause a loss of time after every blast while the bottom is being pumped dry, will lessen the rate of sinking far more than can be calculated by adding together the actual delays.

Ventilation. — Foul air and powder smoke in the shaft bottom hinder work almost as much as water. As a rule vertical shafts ventilate themselves surprisingly well to a depth of 400 to 500 ft., but at greater depths and sometimes at much lesser depths, artificial ventilation must be resorted to. The cheapest method, where the natural draft needs only a slight assistance, is an "air box," or wooden pipe carried up one compartment of the shaft; into this box is turned a jet of air or steam or the exhaust of the pump, if one is used. The box is built of 1 × 12 in. boards. Another way to help natural ventilation in a rectangular shaft is to

divide the shaft into two compartments with a brattice attached to a row of buntons; one compartment will then establish itself as an upcast, the other as a downcast. If all steam pipes to pumps are kept in one compartment this action is certain to occur. In any case steam pipes should be kept together in one end of the shaft.

In deep shafts positive ventilation is best assured by the use of a fan or blower discharging into a large air pipe carried down the shaft and lengthened from time to time as the shaft deepens. A 15-in. standard volume blower, engine- or motor-driven, is sufficient to ventilate a shaft to any ordinary depth. The pipe may be made of boards, canvas, or light, galvanized sheet iron. The latter, although more expensive than wood or canvas, is air-tight and is not liable to injury from concussion.

Progress. — Progress in shaft sinking is influenced by so many different conditions — quality of rock, size and shape of the shaft, presence or absence of water, efficiency of labor and plant — that it is very hard to make any general statements concerning it. The best progress records are made in deep rectangular shafts on the Rand, in Transvaal, South Africa. These shafts, as has been said before, have a section about 9 × 26 ft. in the rock; work is carried on by three 8-hour shifts 7 days a week; two compartments are used for hoisting, and every man that can be worked is put into the shaft. Kaffir labor is not only cheap, but the Kaffir will work under conditions of crowding to which a white man will not submit. The records made in several South African shafts are given in Table 1: the average progress is seen to be about 135 ft. per month, and the maximum 213.5 ft.

The progress in this country under normal conditions ranges from 60 to 80 ft. for rectangular timbered shafts, although very much higher speeds are sometimes reported. The soft shale in the coal fields of the Middle Western states is easy to drill and shoot. Good records are made in Kansas and Southern Illinois. An account of a shaft near Atchison,

Kan., published in the *Engineering and Mining Journal* for July 26, 1902, states that the daily progress in soft shale was 7 ft. No monthly figures were given. A good record was recently made on a 17-ft. circular shaft in the "Hudson River shale" (dark blue sandstone and sandy slate) on the New York Aqueduct. The system of drilling and mucking used at this shaft is described above under (*e*); the rock was quite hard but broke readily. The average progress made here is shown in the tabulation of American shafts, Table 2. The best month's work is 177 ft. No work was done on Sundays. The writer believes this to be a record for American shafts.*

The rate of progress in the European circular shafts lies between the American and the African rate. The rock penetrated is in general softer than that found in this country.

Tables 1 and 2 give the dimensions of a number of shafts and the progress made in them. Wherever obtainable, the nature of the rock penetrated and the cost per foot is given. The figures were obtained from various articles in the technical papers, from the proceedings of various mining institutes, and from the writer's own records; some of the South African data were taken from the "Deep Level Mines of the Rand," by G. A. Denny, 1902.

Cost. — Cost figures cover a wider range than progress figures and are harder to get. The cheapest shaft on record is the one near Atchison, referred to above, the cost of which, as stated, was $7 per foot. This cost stands alone in its glory as the tabulated figures show. Mr. Henry Rawie published in *Mines and Minerals* an itemized statement of the costs of a shaft sunk in West Virginia, in 1906. These ran as follows:

* Since the above was written, the Breakneck Shaft on the New York Aqueduct was sunk 183 ft. in a month. The rock was hard granite. The system used was the same as at No. 1 Moodna, but six $3\frac{5}{8}''$ drills on tripods were used on the drilling shift. One mucking shift only was worked on Sunday; no drilling shift.

Hoist Shaft, 14 ft. × 22 ft., 180 ft. Deep

	Per Foot
Labor, sinking and timbering	$24.70
Plant	5.55
Superintendence	
Explosives	3.88
Coal	2.55
Timber	6.67
Miscellaneous	5.55
	$48.90

The sinking costs of a pair of shafts sunk in Western Pennsylvania a year later were as follows:

Hoist Shaft, 13 ft. × 26 ft., 422 ft. Deep

	Per Foot
Labor, sinking	$51.00
Plant	2.40
Superintendence	4.35
Explosives	2.75
Coal	5.50
Oil	.60
Freight	.50
Miscellaneous	7.90
Total	$75.00

Air Shaft, 13 ft. × 22 ft., 383 ft. Deep

	Per Foot
Labor, sinking	$57.50
Plant	2.40
Superintendence	4.90
Explosives	3.00
Coal	6.05
Oil	.60
Freight	.50
Miscellaneous	7.14
Total	$82.09

Water per minute: Hoist shaft, 50 gallons; air shaft, 120 gallons.

Costs have risen greatly in the last decade, since no substantial improvements in methods or machinery have been made to offset the increase in wages. Contract prices are

TABLE 1. PROGRESS IN SINKING SOUTH AFRICAN SHAFTS

	Kind of Rock	Size	Depths Between Which Average Progress is Figured, Feet	Cost per Foot	Average Progress per Month
Cinderella Deep	Quartzite or dike	9′ 8″×33′ 6″	0 to 3900	$104.45	90.0
Angelo Deep	Quartzite or dike	9′ 4″×24′ 4″	0 to 239	81.80	119.5
Simmer West	Quartzite or dike	9′ 4″×28′ 4″	0 to 120	99.70	120.0
Knights Central	Quartzite or dike	9′ 4″×29′ 4″	0 to 264	80.90	132.0
Catlin	Quartzitic sandstone	9′ 8″×29′ 8″	0 to 1839	—	145.0
Howard	Quartzitic sandstone	9′ 8″×29′ 8″	0 to 1767	77.86	146.0
Rudd	Quartzitic sandstone	9′ 8″×29′ 8″	0 to 1326	—	175.0
Wilmer	Quartzitic sandstone	9′ 8″×29′ 8″	0 to 1504	—	187.0
Nigel Deep (incline)	—	7′ ×14′	511 to 1206	—	173.7
New Kleinfontein Co.	—	—	858 total	—	171.6

Best monthly records: Howard Deep, 203 ft.; New Kleinfontein, 213.5.

TABLE 2. PROGRESS IN SINKING AMERICAN SHAFTS

	Kind of Rock	Size	Depth Feet	Cost per Foot	Average Progress per Month
Lincoln Gold Mine, Cal.	Greenstone and slate	9′ 8″×18′ 8″	740	$37.92	61.0
Federal Lead Co., S. E. Missouri	Magnesian limestone	13′ 8″×23′ 8″	418	—	69.7
Tamarack, Mich.	Trap	10′ 6″×31′ 0″	4580	99.36	70.5
United States Coal and Coke Co., Tug River, W. Va.	Sandstone (hard gray)	19′ 4″×33′ 0″ elliptical	170	75.00 (unlined)	69.3
Selinsgrove, W. Va.	Sandstone and slate	14′ 9″×30′ 4″	202	—	86.5
Old Dominion Copper Mining and Smelting Co.	—	9′ 4″×28′ 4″	1025	87.00	41.0
M. R. C. C. and C. Co., Fayette City, Pa.	Slate	10′×16′ 4″	207	54.00	102.0
Struthers Coal and Coke Co., New Salem, Pa.	Slate and limestone	12′ 6″×26′	529	—	70.0
New York City Aqueduct, No. 1 Rondout Siphon	Shale	17′ circular	166 to 593	—	107.0
New York City Aqueduct, No. 1 Moodna Siphon	Hudson R. shale	17′ circular	200 to 585	* —	143.0
New York City Aqueduct, Breakneck Shaft	Storm King granite	17′ circular	10 to 568	* —	151.0

Best monthly records: No. 1 Rondout, 138 ft.; No. 1 Moodna, 177 ft.; Breakneck, 183 ft.

* Lining not included.

not generally obtainable, as most shafts are put down by private corporations, but prices high enough to include a good profit to the contractor eight to ten years ago would not cover his costs to-day.

Twenty-five shafts ranging in depth from 350 to over 1000 ft. are required for the portion of the New York Aqueduct now under construction. All but two of these have been let by contract, and the bid prices are public property. The bids, however, are unbalanced in every case, and do not give a fair idea of shaft prices. They range from $175 to $350 per foot.

CHAPTER VI

THE SINKING-DRUM PROCESS. MAMMOTH PUMP. THE FREEZING PROCESS

Sinking-drum Process. — For sinking through the very great depths of water-bearing sand and clay that exist in some of the German mining districts, a method has been developed that does not require any hand work in the shaft bottom until the lining is completed to rock. The shafts are necessarily circular and are lined with cast-iron tubbing. A heavy masonry caisson, with an inside diameter, somewhat greater than that of the finished shaft desired, is first constructed and sunk for 50 or 60 ft., as described in a previous chapter. If the ground beneath the cutting edge is sufficiently firm, it is leveled off and a foundation ring of masonry built under the tapered part of the wall. If not, a concrete floor is laid over the bottom (under water if necessary) and the caisson is pumped out. A heavy iron ring projecting inside the face of the wall all around is built into the masonry foundation ring or into a groove cut in the wall above the concrete floor. A second ring, placed near the top of the caisson, is connected to the first with heavy iron rods, and the space between the rings and around the rods is filled with masonry, forming an inner tube. The upper ring projects inside this inner tube and serves as a base for a circle of powerful hydraulic jacks acting downward.

A very strong cast-steel shoe or cutting edge with an outside diameter slightly less than the inside diameter of the tube is then assembled on the shaft bottom, and rings of cast-iron tubbing bolted together are built up from the top of the shoe to the heads of the jacks. If a concrete floor has been laid it is broken up with a huge churn drill, excavation

is started with a grab bucket or some other mechanical digger, and the shoe and tubbing commence to sink of their own weight. The inner masonry lining acts as a guide for the iron sinking drum, and must therefore be built with its axis exactly vertical, correcting any deviation that may have occurred in sinking the caisson. The rubbing surface is usually formed by I-beams built into the masonry.

When motion ceases, the jacks are brought into play and the drum is forced down, additional rings of tubbing being built up under the heads of the jacks. When the first drum can be forced no farther, the bottom of the shaft is plugged with concrete, the water is pumped out, and a second sinking drum built up inside the first. The concrete is broken up as before, the jacks shifted so as to engage the top of the inner drum, and sinking is resumed. As many as four drums have been used, reaching in one place a depth of 508 ft.

The three methods used for excavation under water inside the drum are:

The Grab Bucket. — The action of a clam-shell or orange-peel bucket is too well known to require explanation. Either bucket will handle coarse sand, gravel, and boulders to advantage, but will not retain fine wet sand through a long hoist, and will not dig tough clay.

The Sack Borer. — This is a gigantic auger with the rigid stem extending up the center of the shaft, Fig. 41. The stem is constructed of heavy flanged pipes bolted together, and is terminated at the upper end by a splined section which serves as the shaft of a large horizontal worm-wheel. A hoisting rope, leading to a powerful engine and attached to a swivel at the top of the splined section, suspends the borer.

The stem is turned by an engine acting through the worm-gear and its worm, and is lowered gradually by the hoisting rope. When the top of the splined section reaches the worm-gear, it is disconnected from the stem proper and raised, and another section of standard pipe is added beneath it. Cross-arms, fitted with rollers at their ends, are attached

to the stem at intervals; the rollers bear against the sides of the completed shaft and prevent the stem from buckling.

The material cut by the borer is collected in two heavy

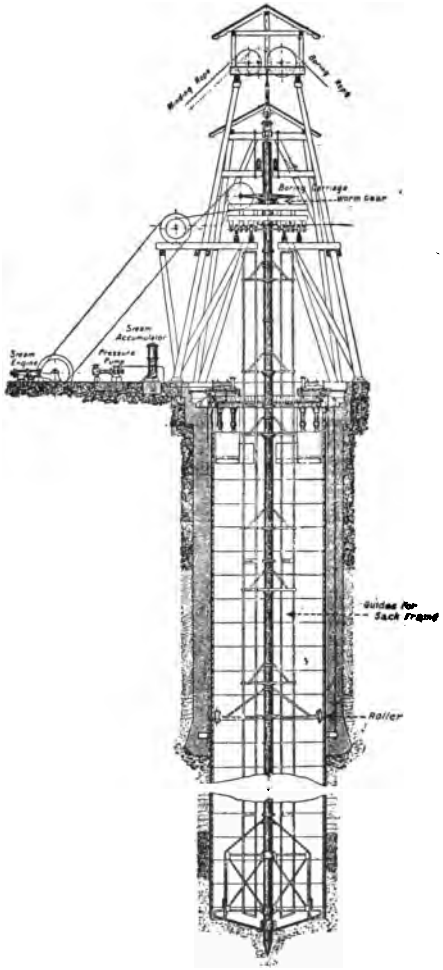


FIG. 41. — Sack Borer

canvas sacks fastened to the backs of the cutters. Formerly they were rigidly attached, and the whole apparatus was hoisted every time the sacks were filled. Now, however, the sacks are mounted on frames sliding on two pairs of

guides attached to the cross-arms on the stem, and are hoisted by light, independent engines. The sack borer is adapted to clay and sand.

The Mammoth Pump. — This is an application of the air lift, used in conjunction with a percussion borer or large churn drill, Fig. 43. A discharge pipe *A*, open at both ends, is carried down along the boring rod from the surface and is terminated just above the point of the borer. A compressed-air pipe *B* is also carried down the rod and connected into the discharge or suction pipe *A* near the bottom. The

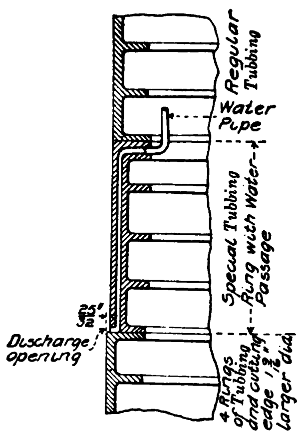


FIG. 42.—Construction of Sinking Drum for Hydraulic Flushing Process

borer being in operation, the air is turned on and a stream of water, mud, and sand is lifted through the discharge pipe. The pump will handle practically any material that will enter the discharge pipe.

The chief difficulty with the sinking drum has been the thickness of iron required to withstand the earth pressure at great depth, and uncertain strains caused by boulders under the cutting edge. The internal flanges on the tubbing cannot be made very wide without interfering with the free passage of boring tools in the shaft, hence the strength of the lining depends on its thickness alone. This has reached $3\frac{1}{2}$ in., and at that thickness collapse has occurred in several

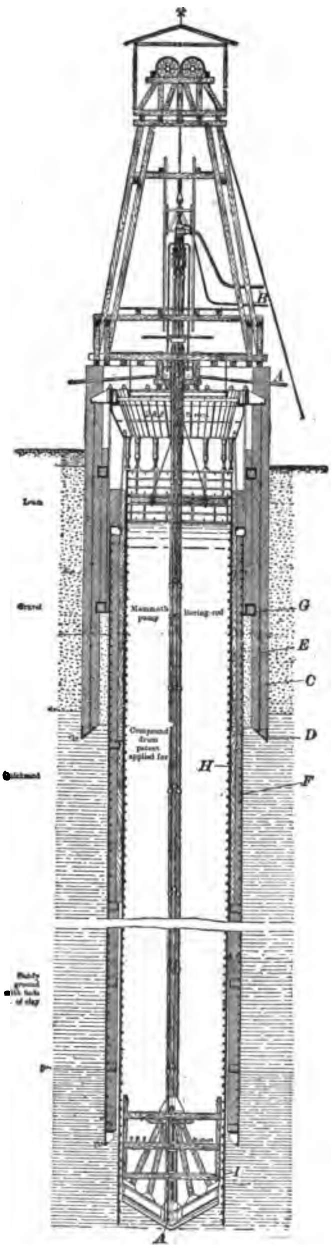


FIG. 43. — Compound Drum and Mammoth Pump and Borer
A, Suction Pipe and Overflow of Muddy Water; *B*, Compressed Air; *C*, Masonry Caisson; *D*, Shoe, Acting on Anchoring Ring; *E*, Anchor Rods.

cases. Further increase is not practicable on account of the weight of the segments and the difficulty of handling them. The cost would also be excessive.

The compound sinking drum (patented in Germany by Mr. Pattberg) is a decided improvement. In this, occasional rings of tubbing are provided with broad internal flanges, and the space between these is filled with concrete or brick, leaving the interior of the shaft perfectly smooth. The masonry not only strengthens the tubbing, but also adds weight where it will do the most good, and expedites sinking.

The friction and adhesion between the ground and the drum have been lessened by hydraulic flushing. For this, the shoe and three or four rings of tubbing immediately above it are made slightly larger than the rest of the lining. In the upper side of the shoulder thus formed, water passages are provided which are connected to a pressure pump. While sinking, the pump is operated and the drum is partially surrounded by a film of water. This expedient has been very successful. (See Fig. 42.)

The sinking drum is sealed to the solid measures by forcing the cutting edge into them by the full power of the jacks. If necessary the shaft can be bored into the rock by the Kind-Chaudron method, as will be explained later. The entire process will probably be made clearer by a short description of an actual piece of work.

Shaft 5, of the Rheinpreussen Colliery, Homburg-am-Rhein, Germany, was expected to penetrate nearly 500 ft. of quicksand and mud. Sinking was started with a brick caisson *C*, Fig. 43, 29.2 ft. inside diameter, with walls about 3.5 ft. thick. This reached a depth of 65 ft. Nine feet of concrete was placed on the bottom under water and the shaft pumped out. The anchor ring *D*, anchor rods *E*, and pressure ring, designed for a maximum pressure of 3000 tons, were erected and a brick inner lining built around the rods, reducing the diameter of the shaft to 25.68 ft.

A compound drum *F*, with an outside diameterof 25.52

ft., and a diameter inside the broad flanges and the brick lining of 21.32 ft., was now built and sinking was started with a percussion borer and mammoth pump. The concrete was bored through in four days, and an average advance of about 5 ft. a day was made in the soft ground. The progress was, in fact, limited by the rate at which tubbing and walling could be built up under the heads of the jacks.

It was possible to force the compound drum to a depth of 245 ft. The shaft was then filled for 60 ft. with sand and gravel instead of concrete, was pumped out, and an inner iron drum, 3½ in. thick and 19.35 ft. in inside diameter, was built up to the jacks. This drum stuck at a depth of 315 ft., 60 ft. of gravel was again filled into the shaft, and a third drum, 17.38 ft. in inside diameter, was built up to the jacks. This was forced to a depth of 343 ft., where the cutting edge stuck in clay solid enough to permit the shaft to be pumped out. A fourth drum, 15.3 ft. in inside diameter, was then built, which reached the solid coal measures at a depth of 508 ft.

Shaft 4 was sunk simultaneously, with exactly similar drums. The third drum reached a depth of 433 ft. before the shaft could be pumped out. The completion of both shafts to the rock took three years.

The Freezing Process. — The great depth to which frost penetrates the ground in Siberia and other cold countries enables shafts to be sunk through soft ground to considerable depths during the winter months. Continued freezing gives the sides all the support that is necessary until rock is reached and a permanent lining built up.

It occurred to F. H. Poetsch in 1883 that this condition could be imitated artificially. His method is to bore a number of holes around and somewhat outside of the periphery of the proposed shaft, and to case them through the soft strata to the rock. A freezing plant is erected at the shaft head, and the brine or freezing solution is circulated down interior pipes and up through the bore-hole casings until the surrounding ground is frozen to a solid mass. The

holes are bored about 3 ft. apart; the form of the frozen ground is consequently cylindrical. At first the cylinder is hollow, but as the freezing continues, it gradually becomes solid ice. Excavation is then commenced, the frozen material being loosened with picks or light charges of explosives.

In Europe 70 or 80 shafts have been sunk by the freezing process, the thickness of the soft ground in some cases reaching 300 ft. Most of these shafts are in France, Belgium, or Germany; a few have been frozen in England by continental contractors. In the United States the process has so far found a very limited application. One shaft in Michigan was frozen through about 100 ft. of quicksand, and an unsuccessful attempt was made to freeze a shaft in Pennsylvania.

A number of European shafts started by the freezing method have been completely lost through some accident. Notwithstanding this, the method is being improved and greater and greater depths are attempted and reached. Water-bearing rock strata are successfully frozen. A shaft in Belgium has been sunk by freezing through 700 ft. of soft ground and wet rock.

A detailed description of the freezing process, written by Mr. Sidney F. Walker, may be found in the August, 1909 issue of *Mines and Minerals*.

The chief difficulties met with in freezing, especially in deep freezing, are deviation of the bore holes, salts in solution in the ground water, bursting freezing pipes, and the tendency of ice to flow under pressure. The first trouble can be met by measuring the drift of the holes, and by boring additional holes when the divergence of those already bored is too great. Salt solutions are of course very hard to freeze, and their presence in the ground necessitates a much longer freezing period than would otherwise be necessary. A burst pipe allows the freezing solution itself to flow into the ground, forming a soft spot that it is almost impossible to freeze at all. The obvious way to prevent this is to use very strong

tested pipe, and it is now found advisable not to circulate the freezing solution through the bore hole casing itself, but to insert an inner and outer freezing tube and to withdraw the casing. The flowage of ice cannot be prevented and limits the depth for which the freezing process is feasible. Hard freezing checks this tendency.

A freezing period long enough to thoroughly solidify the ground is the first essential for successful sinking. The smallest crack or seam which will admit a few drops of water will soon enlarge itself until a disastrous break-through occurs. It is also necessary, from time to time as the shaft is excavated, to support the sides with some form of suspended lining.

The Anhalt Government Salt Mine, at Leopolds-Hall, Stassfurt, is an example of a successful application of the freezing process. Drilling was commenced early in 1899 and 26 holes about 5 in. in outside diameter were drilled on a 26.25 ft. circle and cased to a depth of 325 ft. The drilling was difficult, and was not completed until June, 1900. By this time the freezing plant (which consists at most shafts of two 75 horse-power ammonia compressors) was ready and it was started June 22. Sinking was commenced on September 2, and on September 19, at a depth of 30 ft., a small leak which existed in the middle of the bottom broke through and flooded the shaft. Freezing was then continued until the end of November, and sinking was again started. By the end of February, 1901, 202 ft. had been sunk, and the shaft was then lined with iron tubbing. The space between the tubbing and the rock was filled with concrete mixed with a solution of calcined soda. Periods of sinking and lining then alternated, until on July 4, the shaft was lined complete to the bottom of the frozen wall. The total time required for a depth of 325 ft. was therefore two and one-half years, an average progress of 11 ft. per month.

The Chapin Mine Co., Iron Mountain, Mich., decided to sink a shaft in the center of a small valley crossing its property. Attempts to sink by ordinary methods having failed,

in 1887 a contract was let to the Poetsch-Sooysmith Freezing Co. to sink the shaft by the freezing process. At the site of the shaft the rock was covered by 95 ft. of quicksand, gravel, and boulders. The sand had some clay mixed with it, contained 1 per cent. of water, and would flow almost like water.

The installation of the freezing pipes was performed by the Chapin Mine Co. itself, and was finished in the summer of 1888. Twenty-six 10-in. bore holes, spaced evenly on 29-ft. circle, were driven and cased to rock, great difficulty being experienced in keeping them vertical on account of the boulders. Eight-inch freezing pipes $\frac{3}{8}$ in. thick, flush inside and out and closed at the bottom, were lowered into the holes and the casings were then withdrawn. Inner tubes $1\frac{1}{2}$ in. in diameter were lowered into the freezing tubes, their lower ends being kept 8 in. above the bottom. The upper ends of the tubes were connected, as shown in Fig. 44, to the brine pipes of a 50-ton-per-day capacity Linde freezing plant operated by a 55 horse-power engine, driven by compressed air. Two hundred cubic feet of brine consisting of a 25 per cent. solution of calcium chloride was used for the freezing fluid, the entire quantity making a circuit every thirty-three minutes.

Excavation and timbering were started fifteen days after freezing was begun and were continued for seventy-eight days, when rock was reached in one end of the shaft. During this period two and a half days were lost by the interruption of the air supply to the engine. Some water had been finding its way up through the unfrozen core in the middle of the shaft; the quantity now increased and sand began to come in with it. The shaft was at once filled with water and an additional freezing pipe put down. Four months and a half after freezing was begun the shaft was sunk 7 or 8 ft. into the rock. At this point enough water found its way through the fissures in the rock to thaw out the sand at the rock surface, and it was necessary to again flood the shaft. Before this was done, however, a coil of pipe was

suspended at the rock surface and connected to the freezing machine. This successfully stopped the leak, but six weeks more were lost. The shaft was sealed to rock, and the ice machine shut down on June 6, 1889, after running just two hundred days.

The shaft was sunk rectangular 15 ft. 6 in. × 16 ft. 6 in.

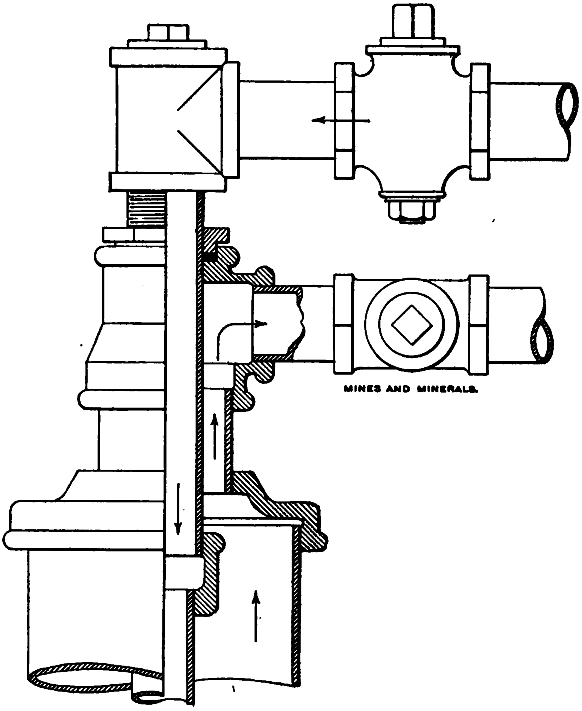


FIG. 44. — Connections of Top of Freezing Tube, Chapin Shaft

in plan, and was lined with 16 × 16 in. timber sets spaced about 4-ft. centers on top, and skin to skin at the bottom. The frozen sand was blasted out with lime, black powder, and finally dynamite.

In 1889 the Mt. Lookout Coal Co. started to sink two shafts near Wyoming, Pa. The test holes showed 32 ft. of dry gravel and 70 ft. of quicksand over the rock. While the first shaft was being sunk by the pneumatic process, an

attempt was made to sink the second by the freezing process. Bore holes were put down from 5 to 7 ft. apart in a circle around the proposed shaft, and cased through the surface and 5 ft. into the rock. A freezing mixture was then circulated in the pipe for seven weeks, at which time the caisson of the first shaft reached rock. It was then discovered that the rock, instead of being solid as supposed, was fissured for 18 ft. below the surface. As a large inflow of water occurred in the fissures, the company decided that it would be impossible to successfully seal off the water in the second shaft with the freezing tubes only 5 ft. in the rock, and the attempt was abandoned. The shaft was then sunk by the pneumatic process, and although some time had elapsed between the abandonment of the freezing and the sinking of the caisson, the ground was found to be still frozen hard.

The writer wishes to acknowledge his indebtedness to Mr. J. Riemer, from whose book, "Shaft Sinking in Difficult Cases,"* he got many facts about the sinking drum and freezing processes in general, and a description of the European applications. The descriptions of the American freezings were abstracted from the Transactions American Society Civil Engineers for June, 1904.

* "Shaft Sinking in Difficult Cases," by J. Riemer, translated from the German by J. W. Brough. J. B. Lippincott & Co., Philadelphia, 1907.

CHAPTER VII

THE KIND-CHAUDRON BORING PROCESS. CEMENTATION OF WATER-BEARING FISSURES

SINKING in wet rock may be accomplished in two ways: mechanically, by breaking and removing the rock under water; by hand, by closing the seams in the rock, thus preventing the inflow of water, or by lifting the water as fast as it flows in.

The first plan can be carried out in one way only — the boring process.

The second is accomplished by the freezing process, already described, and by direct cementation of the fissures of the rock: water is most frequently lifted by sinking pumps suspended in the shaft, although the old Cornish "spear-rod" pump is still sometimes used for large quantities of water. A system of water hoisting has also been developed.

The Boring Process. — The Kind-Chaudron boring process has previously been referred to as a process devised for sinking through rock measures containing such quantities of water that hand sinking is impossible. It is exclusively a European method, and so far no shafts have been bored in this country. The process was originated by M. Kind, a well borer, in 1849. Between that date and 1854 he attempted to sink three shafts in Moselle and in Westphalia, but failed owing to the inadequacy of wooden tubbing. The scheme was then taken up by M. J. Chaudron, a Belgian engineer in France, and was improved by him to such an extent that his name is now always associated with that of Kind. Subsequent improvements of value have been made by Riemer and others, and have been patented in Europe; at present the firm of Haniel &

Lueg, of Dusseldorf, controls many of these patents and is best equipped for boring shafts.

Kind's original plan was to bore the shaft in one operation. The difficulty of collecting the broken rock made it advisable to bore in two stages, and a small hole, having a diameter one-third to one-half that of the finished shaft, is now bored in advance. The muck in this is removed by a special bucket with flap valves in the bottom, so arranged that as the bucket is lowered the muck will enter. When the bucket is raised the valves close.

The small shaft serves as a guide for the large boring tool, as well as for a collector for muck, and it is usually bored about 100 ft. ahead of the large boring. The cutting edges of the large borer slope down toward the center; the borings, therefore, slide into the small shaft. The large tool thus has always a clean surface to work on.

Boring is usually adopted as a last resort. In regions where large flows of underground water are expected, the shaft is sunk by hand until the water-bearing strata are reached and is then cleared for boring. Care must be taken to keep the shaft free from timbers, permanently fastened pumps, and pipes, etc., so that when it is flooded all impediments to boring can be hoisted out. If this is not done, it will be necessary to cover the bottom of the shaft with a thick layer of concrete, deposited under water with a grab bucket, in order to permit the shaft to be pumped out and cleared.

When boring is started, it is carried through the water-bearing strata and some distance into the impervious ground beneath. The shaft is then lined with rings of cast-iron tubbing; the placing of this tubbing is the most ingenious feature of the boring process. (See Fig. 45.)

After the shaft has been cleaned out and the boring tools removed, a heavy platform is built over the shaft and upon it the "moss box" is erected. This consists of two rings of heavy tubbing, forming a large stuffing-box which is filled with moss, and is so designed that an upward pres-

sure on the lower ring will force the moss out against the sides of the shaft. The moss is covered with wire netting to keep it in place, and the diameter of the whole is slightly less than that of the shaft. On top of the moss box is bolted a ring, fitted with a heavy arched bulkhead that closes the

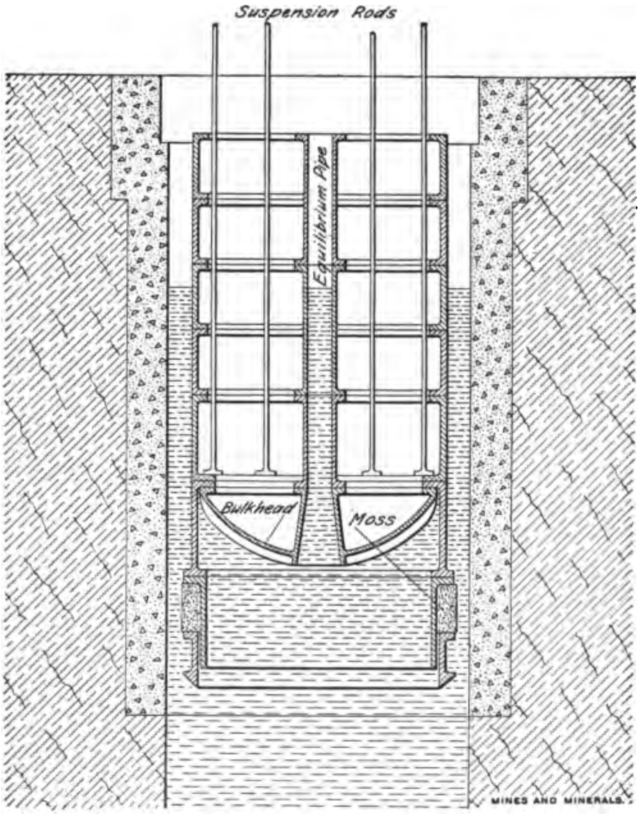


FIG. 45. — Tubbing and Moss Box

shaft. The whole structure is then lifted by heavy jackscrews and, after the platform is removed, is lowered into the shaft. It is then hung from beams placed across the shaft, the jackscrews are disconnected and withdrawn, another ring of tubbing placed on the beams, and the jackscrews reconnected. The beams are taken out and the

ring is lowered into place and bolted up. The process is then repeated.

Since each ring of tubbing weighs less than the water it displaces, after enough have been added the whole column of tubbing will float. The hanging rods are then dispensed with and, as each ring is bolted on, the tubbing is sunk by admitting water. This is continued until the moss box reaches the bottom of the shaft. The whole column is then allowed to fill with water, and, all buoyancy being removed, the entire weight of the tubbing serves to crush the moss outward against the sides of the shaft. A water-tight joint is thus made at the bottom.

The space between the tubbing and the sides of the shaft is then filled with concrete, and, after this has set long enough to thoroughly harden, the shaft is pumped out and the bulkhead removed. The concrete is usually placed with small flat buckets lowered with ropes.

The boring tools, borers or "trepans," Fig. 46, are made of cast steel provided with inserted teeth, and weigh about 10 tons for the small and 20 tons for the large tool. They are suspended by heavy timber rods from a walking beam operated by a single large, vertical steam cylinder. Between the walking beam and the rods a chain connection is provided, by means of which the borers can be lowered as the hole deepens. At the "bore master's" platform on top of the shaft there is a swivel connection and a long lever for rotating the borer slightly between blows.

The head-house is a tall structure with two wings in which are stored the various tools. All are hung from small trucks which can be readily run out over the shaft. Two hoist engines and cables are provided, one for the bucket and the other for the borers and tools.

Considerable difficulty is encountered in boring through fissured ground and through strata of soft material. In the first case the teeth of the borers are liable to breakage; in the second, large masses of material fall out of the sides of the shaft, sometimes burying the borer. A special tool has

been devised for fishing out broken teeth, large pieces of rock, etc. A falling in of material is prevented by sheet-iron cylinders, lowered from the top and suspended by flat ropes. These cylinders have no hydrostatic pressure to resist, hence need not be heavy. They are built of $\frac{3}{4}$-in. plate, in lengths up to 60 ft.

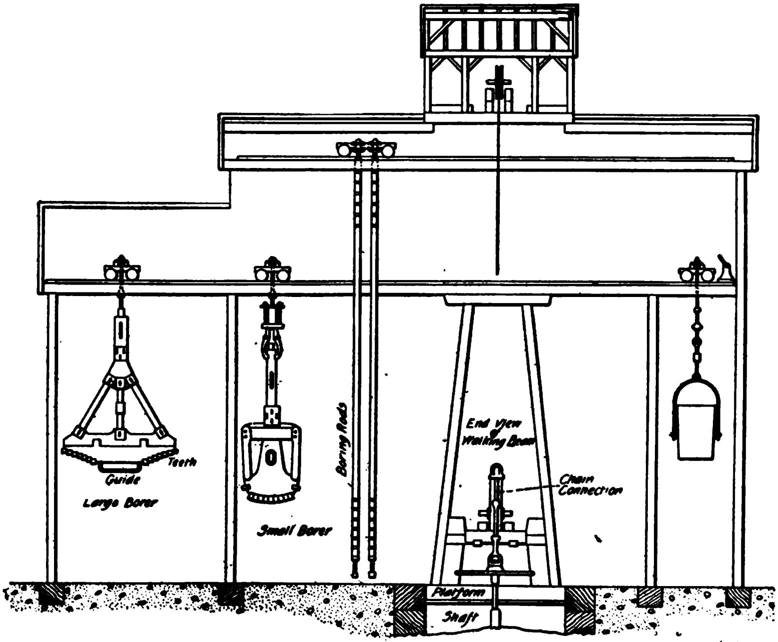


FIG. 46. — Cross-section of Boring Tower

It has not been found practicable to use segmental tubbing rings for lining bored shafts, owing to the difficulty of making the vertical joints water-tight. The maximum diameter at present, therefore, is limited by the size of the single ring which can be transported — about 14 ft. diameter. The boring is made 18 in. to 3 ft. larger, depending upon the character of the ground. Ordinarily the small borer is about 8 ft. across, and the large one $15\frac{1}{2}$ ft. for 14-ft. tubbing, but if much bad ground is expected and the use of

several sheet-iron cylinders is contemplated, the large borer is made 16½ ft. or 17 ft. across to start with.

The speed made in boring shafts has varied so greatly that it is hard to give definite figures. Under favorable conditions the small tool will advance 20 in. per day, and the large one 7 or 8 in. If to the time required for actual boring is added that taken for lowering sheet-iron cylinders and tubbing, it will be seen that an average progress of 8 to 10 ft. per month is all that can be expected. The costs of the boring process are, in consequence, exceedingly high, but for the very difficult sinking conditions obtaining in some parts of Europe it is the only process that is unfailingly successful.*

Direct Cementation. — The injection of cement grout under pressure into fissured rock has been attempted only recently. Immediately around the proposed shaft a number of holes are drilled through the fissured rock into the solid measures beneath, and grout is forced into them until all crevices are filled. It is then allowed to set, and, if the work has been properly done, sinking can be continued in the dry.

The water-bearing fissures can best be located by using core drills rather than percussion drills in boring the holes. If only one crevice exists, the grout will flow directly into it; if, however, the rock is fissured for some distance, while grout is flowing into the upper cracks, the hole beneath them may become blocked before the lower cracks are filled. In this case the water will not be completely shut off.

Up to the present time the blocking of the fissures in any considerable depth of rock has only been accomplished by successive cementations. This was done in the two cases described below. The writer believes, however, that if the holes are bored entirely through the wet rock, a method can be devised for filling the cracks from the bottom up. A plan that might be worked out would be to case the holes

* For detailed infomation on this process see: "Shaft Sinking in Difficult Cases," by J. Riemer.

with flush-joint pipes to the bottom, then to gradually withdraw the pipes as the grout is pumped in. The grouting apparatus would have to be so arranged as to permit quick disconnection and reconnection upon the removal of each length of pipe, to avoid the possibility of the grout setting in the pipe while the flow is interrupted.

The following account of the cementation of a shaft sunk by the Mining Society of Lens is an abstract from an account published by C. Dinoire in Volume XXXI of the Transactions of the Institute of Mining Engineers (English):

The Mining Society of Lens decided in October, 1904, to sink two shafts, one by the freezing method and one by hand. The water encountered in the second exceeded the expectations to such an extent that it could not be pumped and the feeders had to be stopped by direct cementation.

This shaft was sunk to a depth of 166 ft. before an inflow of 2200 gallons per minute made cementation necessary. The pumps were worked very hard to hold the water down as low as possible, and two lines of 2-in. pipe, extending from the surface to the bottom of the shaft, were installed. As some of the water came in through a nearly vertical fissure in the shaft bottom, and some through a horizontal seam, one of the pipes was driven into the fissures for 9 ft. and the other was terminated opposite to the seam, Fig. 46. Four 8-in. bore holes, 197 ft. deep, were then put down outside the shaft area. They were spaced evenly 13 ft. from the circumference of the shaft. At a depth of 190 ft. they passed through a bed of very seamy rock. A hand pump was put on each of these holes in order to pump out all sand and mud caused by boring.

Three hundred and sixty sacks of cement mixed as a thin grout were then run into the pipe which terminated opposite the horizontal seam. This took seven hours; the grout mixer was then connected to the other pipe to give the grout in the bottom of the shaft a chance to set. Two hundred and ninety sacks were run into this pipe in three hours, when the lower end became blocked. Ninety sacks

were then run into the first pipe, completely filling it, after which the bore holes were filled. This required 475 sacks. The pumps on the bore holes were worked continuously while the pipes were being grouted.

The grout was allowed to set for nineteen days before the water was pumped out of the shaft. It was then found that the leak was completely closed and a $2\frac{1}{2}$-ft. layer of

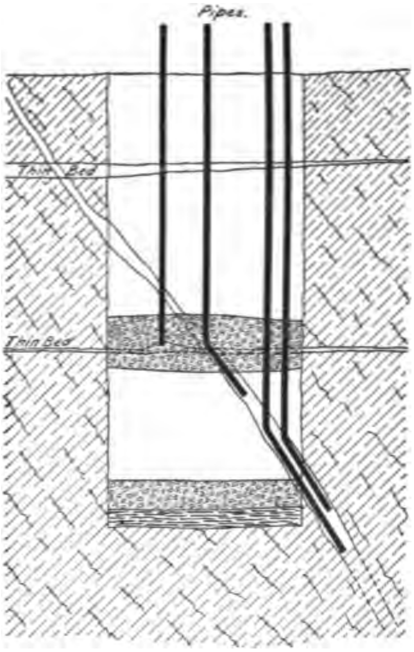


Fig. 47. — Location of Pipes and Fissures in Lens Shaft

grout had formed on the bottom. The rest of the grout, amounting to 282 cu. ft., had run into the fissures.

The bed of grout was sunk through very carefully, and the shaft deepened to 170 ft. and lined to the bottom. At 185 ft. a second inflow was encountered, the water breaking in through the vertical fissure referred to above. Two more grout pipes were inserted, their lower ends being driven 3 and 6 ft. into the fissure. Nine hundred sacks of cement

were run into the longer pipe in nine hours, when the lower ends of both pipes became closed.

After twenty-eight days the water was pumped out and sinking was resumed. The large fissure was found to be this time thoroughly cemented, and further sinking and lining was carried on without particular difficulty.

It was found in the first cementation, where the mixer discharged directly into 2-in. pipes, that considerable air was carried down with the grout. This hindered the flow very greatly, so that in the second cementation the grout pipes were made $1\frac{1}{4}$ in. diameter above water and $2\frac{3}{4}$ in. under water, a high narrow tank was connected with the top of the grout pipe, and a valve was provided to regulate the flow from the tank, which was kept full. The mixer discharged into the tank through a trough, with gratings for removing air.

The more important conclusions reached were:

1. Fissures in rock can be cemented through pipes or bore holes.

2. Sand, marl, boulders, clay, and slime cannot be cemented.

3. Thin beds presenting continuous openings can be cemented by pumping from bore holes outside the shaft.

Direct cementation has also been applied at the Anzin and the Bethune collieries in Europe.

Direct cementation has only been attempted in America in one instance. No. 4 shaft on the Rondout siphon of the Catskill Aqueduct encountered a flow of water of 750 gallons per minute at a depth of 270 ft. The shaft is rectangular with three compartments, measures only 8 ft. 4 in. × 20 ft. 4 in. in the clear, and thus affords very little opportunity for handling large pumps. In addition to this fact the water was strongly charged with sulphureted hydrogen gas, which acted very painfully upon the eyes of the sinkers.

After no progress had been made for several weeks, it was decided to try grouting. Most of the water came directly out of the bottom. The water level was held within

about 5 ft. of the bottom and a number of holes from 10 to 18 ft. deep were drilled with rock drills. Two-inch pipes were connected to these holes, and about 1500 sacks of cement, mixed as neat grout, were forced into them. This reduced the flow of water in the bottom from 525 to about 50 gallons per minute.

In order to block the fissures below the shaft bottom, a diamond drill was set up on a platform at the top of the shaft, and six holes were drilled, each about 95 ft. deep. A column of 3-in. pipe extending from the top to the bottom of the shaft served in each case as a guide for the drill rod. These holes passed entirely through the water-bearing rock, which consisted of a badly fissured sandstone, and penetrated an impervious stratum of grit beneath. Two-inch grout pipes were now connected to these diamond-drill holes and 183 sacks of cement were forced into them. This entirely cut off the water in the bottom.

It was found upon pumping out the water that all the upper fissures were completely filled. When sinking was resumed, however, it was further found that the drill holes had become blocked before the lower fissures were completely filled, and the water, therefore, was not altogether shut off. After the cementation it was, nevertheless, possible to handle the water with pumps and sink about 10 ft. a week in the ordinary way.

In filling all the holes the grout pipes were carried to the top of the shaft. The grout was mixed and fed into a tank attached to the top of each pipe. When no more grout would flow by gravity, the opening in the tank was closed, and air pressure applied on top of the liquid grout. The pressure ranged from 80 lbs. to a maximum of 300 lbs. per square inch, which last was obtained by means of a special air compressor.

NOTE.—For further information about methods of grouting see Appendix A.

CHAPTER VIII

Lifting Water. Horizontal vs. Vertical Pumps. Handling Pumps in Shaft. Cornish Pumps

Moderate quantities of water are ordinarily raised from the bottom of a sinking shaft by one or more pumps, suspended or supported in the shaft just above the bottom, and lowered from time to time as the shaft is deepened. The usual motive power is steam or compressed air; electric pumps are being developed, but so far have not been successful.

The work that a sinking pump is called upon to do is exceedingly arduous. It must first of all be reliable; it must run on gritty water or a mixture of water and air, or sometimes on air alone for a while without injury. The valves, packing, and wearing parts must be readily accessible. It must occupy a minimum space in the shaft, and at the same time be strong and heavy enough to endure collisions with the sides in hoisting and lowering, and blows from flying fragments of rock.

Any one in this country who has tried to sink a wet shaft is more or less familiar with the features of the leading American sinking pumps. Of these the Cameron is the best known, and the Cameron pattern, Fig. 48, now manufactured by a number of firms, certainly comes nearest to filling the requirements. This is built in both vertical and horizontal piston and outside-packed plunger styles, and is marked by the absence of outside valve gear, by the thickness and strength of the castings, and by the accessibility of the water valves and packing.

The manufacturers as a rule recommend the vertical pump for sinking, but the writer's experience has taught

him otherwise. When there is only a slight inflow of water, a small vertical pump with hose connections is certainly very easy to hang in the shaft; on the other hand, a horizontal pump, with a capacity of 150 gallons per minute

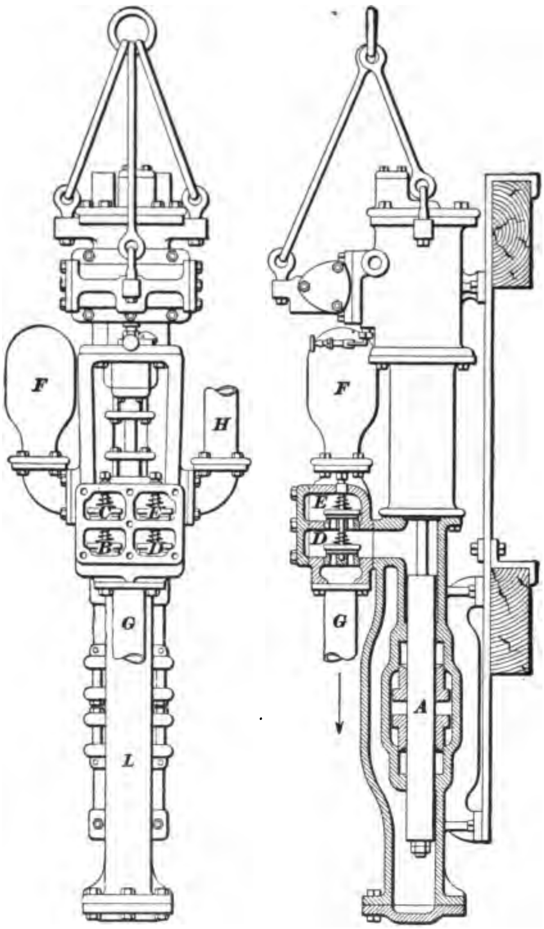


FIG. 48. — Vertical Sinking Pump

or less, will work perfectly when hung with a bridle. Where there is a considerable flow of water, and where the shaft is large enough to accommodate a horizontal pump or pumps of the required capacity, this is the type to use. Where the

shaft is so small that there is not room in it for enough horizontal pumps to take care of the water, a vertical pump is of course a necessity.

The writer's reasons for preferring the horizontal pump are:

1. The horizontal pump is lighter than a vertical of the same capacity.

2. In the larger sizes the horizontal pump is much more accessible, since a man can walk around it and work at any part of it on a level platform. It is necessary to climb 6 or 8 ft. to get from the water end to the steam end of a big vertical pump.

3. By providing a proper bridle, the horizontal pump can be hooked on to and lifted as easily as the vertical.

4. For a pump discharging over 300 gallons per minute, the recoil at every stroke is so severe that hose or other flexible connections will not stand when the pump is hung freely. This applies to the American style of vertical sinking pump, where the center line of neither suction nor discharge coincides with the center of suspension, as well as to a horizontal pump. In both cases it is necessary to furnish rigid support, and it is as easy to set two hitch timbers in a horizontal plane for a horizontal pump as it is to set them in a vertical plane for a vertical pump.

In sinking several shafts in which the flow of water in the bottom varied from 800 to 1500 gallons per minute, the writer has obtained the best results by working along the following lines:

Provide an absolutely reliable boiler plant of ample capacity. Sinking pumps are frightfully uneconomical, requiring from 200 to 250 lbs. of steam per actual horse-power hour; a shaft in which 1000 gallons per minute must be lifted 300 ft. will, therefore, require $\frac{1000 \times 8\frac{1}{3} \times 300 \text{ ft.}}{33{,}000} \times \frac{200}{30} = 505$ horse-power of boilers for pumping alone.

Put in a water ring, Fig. 49, and a stationary pump

wherever it is possible to reduce the water in the bottom by so doing. When the water-bearing stratum has been sunk through, open up a "lodgment" or reservoir in one end of the shaft and install a compound pump.

For handling water in the bottom provide at least 50 per cent. extra pumping capacity; say, four 350-gallon

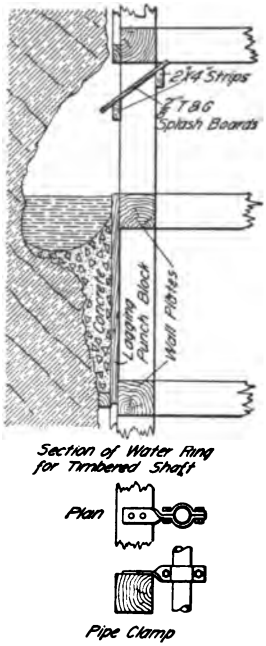


FIG. 49. — Section of Water Ring for Timbered Shaft

pumps for 900 gallons per minute, two in each end of the shaft. Set bearing timbers, Fig. 50, as close to the bottom as is safe, and lower pumps alternately 10 ft. at a time, keeping 10-ft. and 20-ft. flanged lengths of steam, exhaust, and water pipes ready to put on. If each new set of timbers is placed 10 ft. from the bottom of the shaft, the maximum suction lift at any time will thus be 20 ft. Make swinging joints on all pipe lines at the pumps, to take care of vibration and expansion and of variations in the spacing of the

hitch timbers. Do not attempt to lift pumps when blasting; remove suction hose only and shoot carefully.

Provide an independent column pipe for each pump, and keep the pipes in the hoistway. Main steam and exhaust lines should be kept in one end of the shaft for the greater part of their length in order to create an upward current of

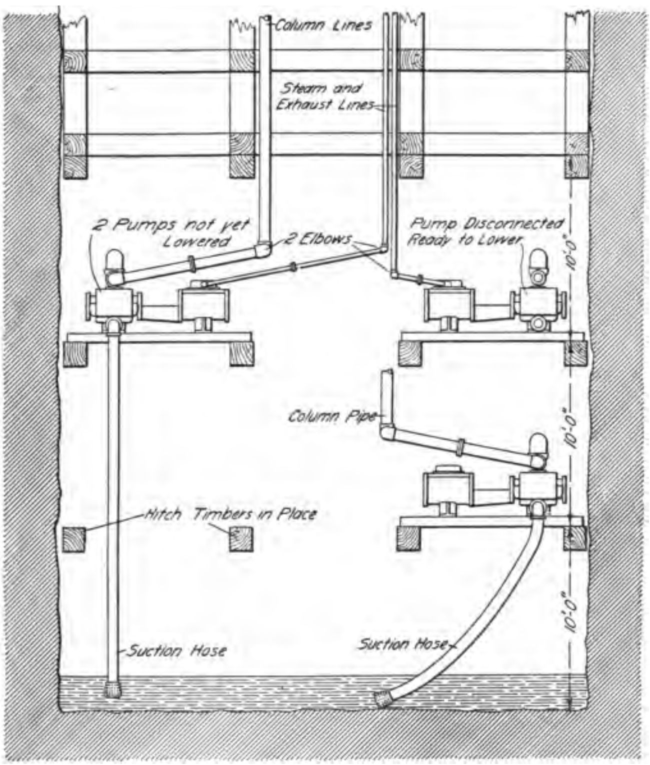


FIG. 50. — Arrangement of Pumps for Sinking

air in that end and assist ventilation. Handle pumps with independent engine, arranged to hoist from any compartment. Clamp pipes to timber every three lengths.

Too much care cannot be taken to obtain tight joints in all pipes, to fasten them securely to the timbers, to keep the pumps in good repair and plenty of spare parts (valves,

stems, packing, etc.) on hand, and to keep the follower bolts and nuts tight. It is advisable to fasten these securely with cotter pins, or by drilling through the heads and wiring them together.

Pumps will run satisfactorily on compressed air if the air is reheated sufficiently to prevent freezing. As a rule, the cost of the air plant makes it imperative to use steam on the pumps. Both steam pipes and exhaust pipes should be lagged with some water-proof covering.

At best, many delays will occur when water is handled. For a shaft making 800 to 900 gallons per minute, 15 to 20 ft. per month is good progress; the labor cost may easily reach $150 to $200 per foot. Sinking with insufficient machinery is impossible.

In this country water is usually regarded as an unfortunate accident, and when encountered is met by begrudged additions to the plant. As a result much time and money are wasted. In Europe, on the other hand, the mining districts have been more fully explored and developed, and the position of water-bearing strata is known. Preparations are made in advance for handling large quantities of water. The shafts are circular and are lined in sections as the sinking proceeds with brick or water-tight iron tubbing; their large diameter and freedom from cross-braces make it possible to use more powerful pumps. An actual measured flow of from 2000 to 2500 gallons per minute in the shaft bottom is as much as has been successfully taken care of in America. In the two English cases cited below two to three times this much water was pumped.

In the Transactions of the Federated Institute of Mining Engineers, Volume III, page 513, Mr. W. H. Chambers describes the sinking of two shafts at Conisboro, Yorkshire. Eight 30 ft. × 7 ft. 6 in. Lancashire boilers were installed, and sinking was then commenced in both shafts simultaneously. The water was handled by pulsometers to a depth of 156 ft., when an inflow of water occurred that made it necessary to put in very much more powerful pumps.

The sinking pumps, Fig. 51, were made by Baily & Co., of Salford, and were designed to run suspended in the shaft without other support than two suspension ropes which also carried all pipe lines. A telescopic suction pipe is provided instead of suction hose, and the axes of both suction and discharge pipes coincide with the axis of suspension. All vibrations caused by the strokes of the pump are, therefore, vertical and cause no dangerous sideways motion in the pipe lines. The pump itself "consists of three hollow plungers; the upper pair are stationary and over them slide barrels which are connected to the steam piston. The third barrel is secured, together with the pair of stationary plungers, to the steam cylinder by means of connecting rods." The pump is thus what is here known as the differential plunger type. Two discharge pipes are led from the top of the upper stationary plungers alongside the steam cylinder, and are joined above it by a tee from which the column pipe rises.

The two suspension ropes are led over pulleys at the shafthead to the drum of a hoisting (or capstan) engine, and the pump and all piping are hoisted and lowered together. A telescopic joint is put on the steam pipe at the shaft head, the discharge pipe is turned sideways over a trough, and the exhaust pipe stands straight up. The arrangement of pump and pipes in the shaft is shown in Fig. 52 and the method of supporting the pipes is shown in horizontal section in Fig. 52*a*.

Six pumps of this type, each with a capacity of 50,000 to 70,000 Imperial gallons per hour at 35 strokes per minute, were needed to sink the shafts to a depth of 300 ft. In this depth the maximum quantity of water discharged from both shafts amounted to 6600 gallons per minute, although the tubbing was carried along with the sinking. Two more pumps were then obtained, and the eight were arranged to lift the water in two stages, as 300 ft. was the maximum lift of each pump. The water was finally shut off at a depth of 395 ft. in one shaft and 369 ft. in the other.

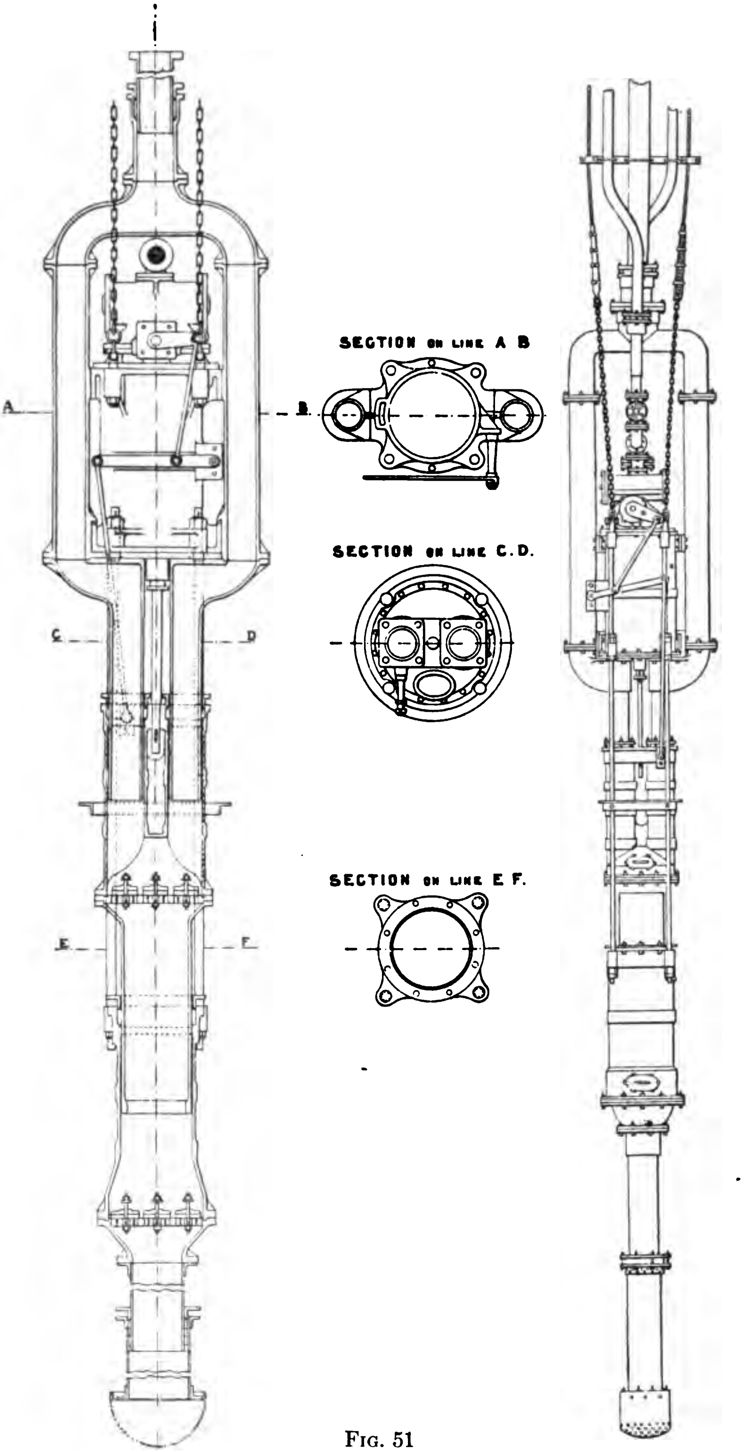

SECTION ON LINE A B
SECTION ON LINE C.D.
SECTION ON LINE E F.
A
B
C
D
E
F

Fig. 51

Mr. Chambers describes the operation of the pumps as follows:

"As the sinking progressed, after the suction pipe was

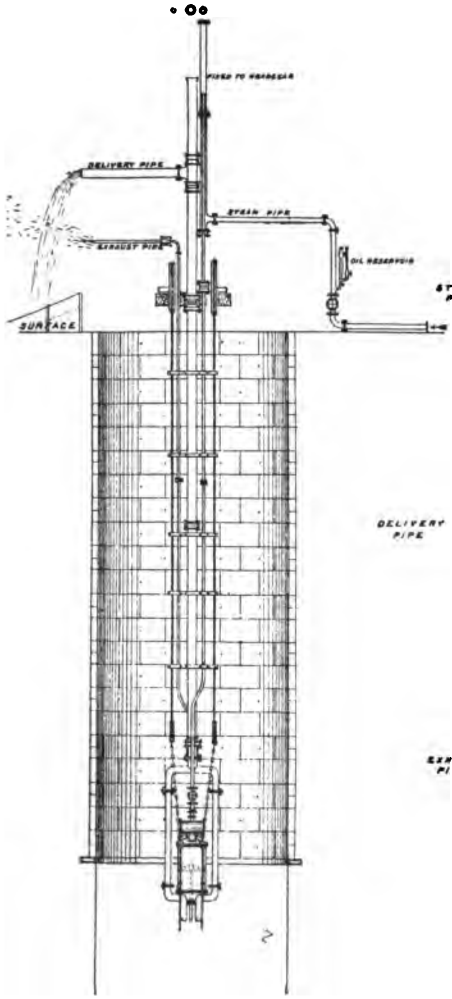


FIG. 52

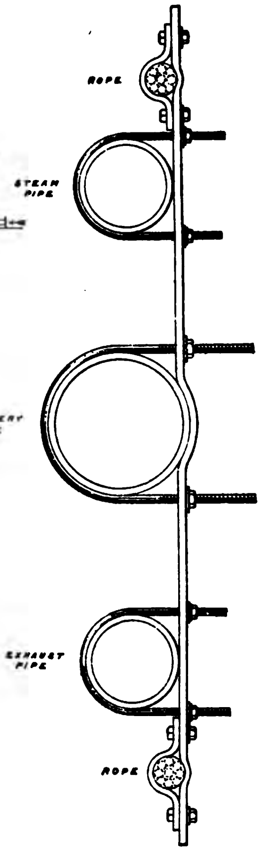


FIG. 52*a*

drawn out to its full extent, the pump with the columns of pipe was lowered by running the ropes off the capstan, and exhaust and water pipes were built as required on top; the

steam pipe, after being drawn its full length out of the stuffing-box, was pushed back and another length inserted.

"A stop valve and a lubricator were placed in the fixed steam pipe on the surface. A lad was in charge to regulate the supply of steam as required, he being in communication with the sinkers in the shaft by means of a signal bell. The speed of the pumps was thus controlled and lubrication effected without any one being in the shaft for these purposes."

Perhaps the most remarkable achievement in the line of wet-shaft sinking that was ever accomplished was the sinking at the Horden colliery in Southeast Durhamshire. This work is described at length in a very interesting paper by Mr. J. J. Prest, the engineer in charge. The paper is published in the Proceedings of the Institution of Civil Engineers, Volume CLXXIII, Part 3.

At this colliery three shafts were sunk, two of them simultaneously; the third was put down to the level at which the greatest flow of water occurred, and there stopped until the other two reached the coal measures. Mr. Prest, after careful consideration, determined to use the old-style Cornish pump and installed a very remarkable plant, comprising over 3000 boiler horse-power and no less than four sets of 30-in. bore by 6-ft. stroke pumps. Each set consisted of a pair of pump cylinders hung so as to balance each other, and capable of being arranged as a high-and a low-lift set. The pumps were driven by the permanent hoisting engines, provided with an extra jack-shaft and gearing.

The maximum quantity of water handled simultaneously from all three shafts amounted to 9230 Imperial gallons per minute, and the maximum from one shaft to 6310 gallons per minute, this quantity being pumped from a depth of 300 ft. The shafts reached an average depth of about 540 ft. before the coal measures were reached and it was finally possible to tub back the water.

A system has been developed in England for hoisting water from a sinking shaft without the use of any high-

pressure pumps. It is known as the Tomson water-winding process. Mr. Tomson puts in his permanent hoisting engine, places guides in the shaft as the sinking proceeds, and uses large tanks for lifting the water. The tanks are filled by low-pressure pumps driven by compressed air and attached to the tanks. This system has been very successful in some instances, but has not been used where the quantities of water were as great as those at Conisboro or Horden.

CHAPTER IX

Shaft Linings

Shafts are usually lined; either in order to exclude water, or to support the sides and prevent the falling of fragments of rock.

The most common lining material — in fact until recently almost the only lining material — used for American mine shafts is timber, ordinarily framed in square sets and lagged with plank. Such a lining cannot be made water-tight and acts only as a support or shield. Wooden caissons and coffers used in bad surface ground are of course built to exclude water, but this construction is not feasible at considerable depths.

European shafts are usually lined with brick walls, built upon cast-iron curb rings set into the sides of the shaft at intervals. The circular and elliptical sections universal in Europe are in fact accounted for by the necessity for arch action in a brick lining. The walls are not designed to absolutely exclude water, but to lead it to water rings at the curbs and prevent it from dripping in the shaft. A brick lining is fire-proof and durable.

Where it is desired to block back large feeders of water, cast-iron tubbing is used. This has already been referred to in connection with the Boring Process. Two styles of it are used in Europe, known respectively as English and German tubbing; the writer knows of no case where it has been used for a mining shaft in this country, but miles of subaqueous tunnel around New York City are lined with bolted cast-iron segments.

In the last decade, concrete has come to the front as a material for lining shafts. It is gradually being realized

that, when properly handled, concrete can be made as water tight as iron; it is stronger than brick and as durable, and is cheaper than either iron or brick. The first shaft in America to be entirely lined with concrete was sunk by the U. S. Coal and Coke Co. at Tug River, West Virginia, in 1903. Since then this construction has been adopted for a dozen shafts or more.

Of the various kinds of shaft lining, timber is the easiest to place and in America is still the cheapest in first cost. This advantage, however, diminishes every year; good timber is scarce and dear to-day, and ten or fifteen years hence — the life of a timber lining — will be scarcer and dearer. A timbered shaft in a mine whose life is expected to exceed the life of the original timber is thus a very doubtful investment.

Considerations of safety present a stronger argument against the use of timber in coal mine shafts. A severe explosion in the mine will wreck the lining and fill the shaft with twisted timber, thus cutting off all hope of escape or rescue from the men imprisoned below. This danger has long been avoided in Europe by the use of walled shafts, and before many years public sentiment in America will demand that it be avoided here. A Pennsylvania law now on the statute books prohibits the use of wood in permanent tipples or breakers within 200 ft. of the shaft head; why should not this law be logically extended to cover timber in the shafts itself?

In ore shafts and construction shafts the same objection to timber does not apply, although the possibility of fire must be considered. This is not often a serious danger as the timbers are usually so wet that nothing short of an explosion could ignite them. A system of reinforced concrete "timbers" which has been proposed and patented is intended to retain the advantages of a rectangular timbered shaft, and at the same time provide a fire-proof lining that is easily placed. It has never been used.

Timbering. Buntons. — In rock that is hard enough to stand without support and is not affected by frost and

moisture, the cheapest construction is an unlined rectangular shaft with several vertical rows of buntons to which the guides and ladders are fastened. These buntons correspond to the buntons and end plates of a square-framed set of timbers, and are set into pockets cut in the rock.

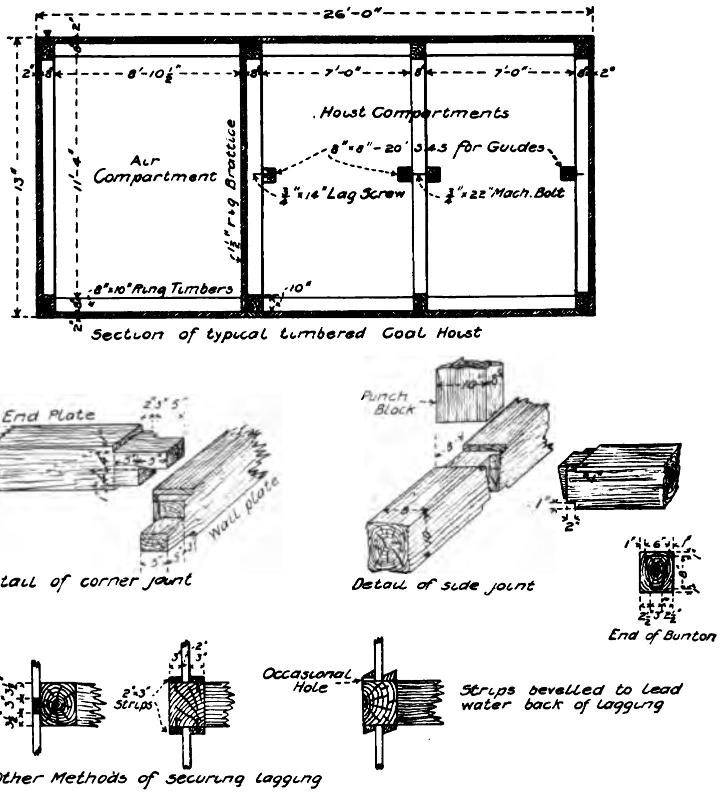


FIG. 53. — Timber Sketches

They must be set correctly in parallel vertical planes, and should be level and in line horizontally, but absolute accuracy in this respect is not essential. The pockets are known as "hitches," the "box hitch" is cut square; the "drop hitch" is cut with the top sloping back so that after one end of the bunton is placed in the box hitch the other

may be dropped into place. The buntons are usually set on 5-ft. centers vertically, so that workmen standing on a platform on one row of timbers can cut the hitches for the next row without scaffolding. (See Fig. 54.)

After the buntons are placed in the hitches they are secured and held in line by oak wedges driven in tight. The hitches are cut just enough larger than the timber to allow for wedging. The depth depends upon the rock; specifications usually call for 12 to 18-in. hitches, but, as a matter of fact, in any rock hard enough to stand without support a 4-in. hitch will break the timber.

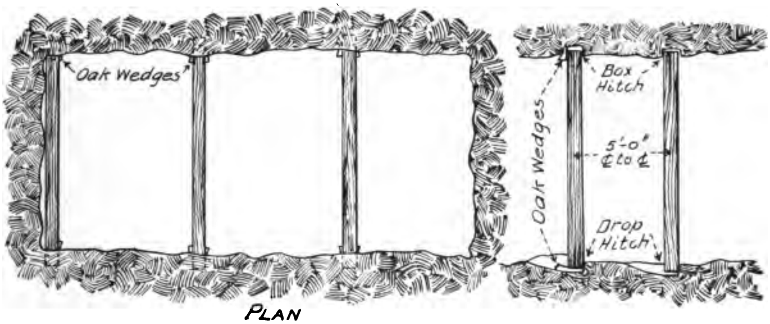


FIG. 54. — Shaft Timbered with Buntons Only

Hitches are usually cut by hand with hammer and bull point, but pneumatic hammers can be used to advantage in hard rock. When working by hand a pair of men (hammersman and holder) should finish a pair of hitches in an eight-hour shift. The labor cost per timber is thus about $5 net, or $7 including headmen, engineers, etc.

Ring Timber. — The commonest form of timber lining, and the one that is used in all large shafts, consists of horizontal square-framed sets, spaced 4 to 6 ft. centers and lagged with 2 to 3 in. plank. (See Fig. 53.)

In a previous chapter, the terms bunton, end plate, wall plate, and punch block were defined as the cross struts, end timbers, side timbers, and posts, respectively, in a square-framed set of timber. Each set consists of two wall plates

and two end plates halved at the corners, and one or more buntons, butted against the inner faces of the wall plates to serve as struts. The buntons also divide the shafts into the requisite number of compartments and afford support for guides, etc. The sets are separated by posts or punch blocks placed at the corners and at the end of the buntons.

Lagging plank are set vertical and close together. They are usually placed back of the timber, and are held by cord wood or slabs packed into the space between them and the rock. This packing also acts as a support for the sides of the excavation. To prevent plank from falling in case of displacement of the packing, they should be well spiked to the timbers top and bottom. The best construction is effected by spiking 2×2 in. strips horizontally in the middle of the outer faces of the wall and the end plates; the lagging boards are then cut two inches short of the center to center spacing of the sets, and are inserted between the strips.

In hard rock packing is not necessary, but lagging is usually needed to prevent water from splashing into the shaft and to lead it to the rings. In this case, the lagging boards are placed between the timber sets and are held by strips nailed to the top and bottom faces of the timbers. Sometimes these strips are beveled so as to lead water to the back side.

When a shaft has been sunk without support as far as the condition of the sides will permit — say 50 to 100 ft. — a set of hitch timbers (dead logs or bearing timbers) is placed as a foundation, and the timbering is built up through the unlined section. The hitch timbers are set into hitches cut in the rock as described above, and must be perfectly level and in line. Since they are to carry a great weight the hitches must be deep enough to afford a bearing equal in strength to the timber. The hitch timbers are often made deeper than the ring timbers; 8×12 in. hitch timbers, for instance, for 8×10 in. ring timbers. A heavy floor is built over the hitch timbers between the first set of timber and the wall, to carry the packing. (See Fig. 58.)

Each set of timbers must be securely blocked and wedged in the corners and opposite the edge of the buntons. The lagging and packing are then finished before the timbers for the next set are lowered. The workmen stand on planks laid across the buntons and raised as each set is completed. In order to avoid splicing, the wall plates for the two or three closing sets (joining to completed timbering above) must be lowered into the shaft, laid upon the timbers already placed, and then raised horizontally.

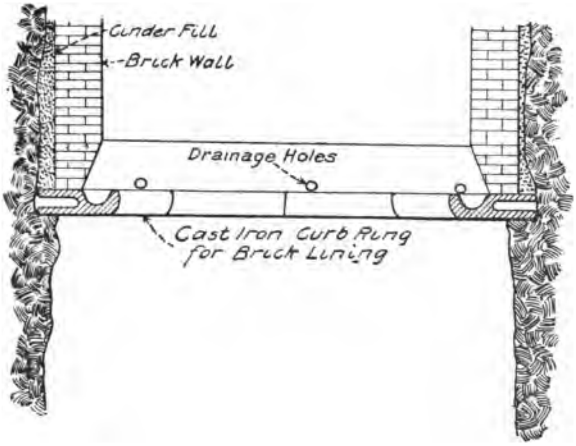


FIG. 55. — Brick Shaft Lining

Corner joints should be framed so as to develop the full strength of the timbers. Punch blocks and buntons are usually notched into the wall plates, being thus secured laterally; the punch blocks are allowed to extend out under the ends of the buntons to provide vertical support. In addition, keystoned shape notches are often cut in the wall plates, into which the ends of the buntons are fitted.

The cost of placing ring timbers of this type varies from \$20 to \$30 per M. ft. B.M.

In small shafts, the lagging plank are often placed horizontally and spiked together, and are notched into each other at the corners. This gives all the support that is required in a small square shaft or well; in a compartment

shaft, pairs of vertical timbers serving both as posts and girders are placed against the side, and buntons are set between them. Vertical nailing strips are also put in the corners. (See Fig. 58*a*.)

Brick. — The thickness of a brick lining varies from 9 to 18 in., depending on the size of the shaft and the nature of the rock. A 13-in. wall is the usual thickness for a 16-ft. shaft. The wall is built in sections 50 to 100 ft. long, each of which is founded on a curb of wood or iron built in segments and set into a groove in the side of the shaft. This groove is cut by hand, the bottom being made perfectly level, and the curb is carefully wedged into shape exactly concentric with the shaft. If much water leaks into the shaft in the section that is to be lined, the curb is made of iron and the space behind it is filled with wooden blocks and wedges driven in tight, as will be described in detail later. A water ring is cast on the inside of the curb, and drainage pipes leading through the lining to the ring are provided. (See Fig. 55.)

The work of setting the curb and building the wall is done on a suspended scaffold which is raised as required by a special engine at the surface. The wall is built very rapidly as several masons can work without interference — six masons, if kept supplied with brick and mortar, can easily build 6 to 8 ft. of wall per shift.

In deep shafts recently sunk in England, the work has been so arranged that sinking and lining are carried on simultaneously. Two buckets are used, one of which hangs in the center of the shaft, and passes through a hole in the walling scaffold. The other hangs sufficiently off center to clear the sinking bucket, and is used for supplying material to the masons. The ropes which suspend the scaffold also serve as guides for the buckets. This method is only feasible for large shafts.

The brick should be made of good clay, burned hard enough to withstand the action of water. Mortar is made of quick-setting Portland or hydraulic cement and is used

as sparingly as possible. The space back of the wall is filled with concrete, tamped clay, or cinders.

Iron Tubbing. — Both English and German tubbing consists of cast-iron segments and is built up in rings. The

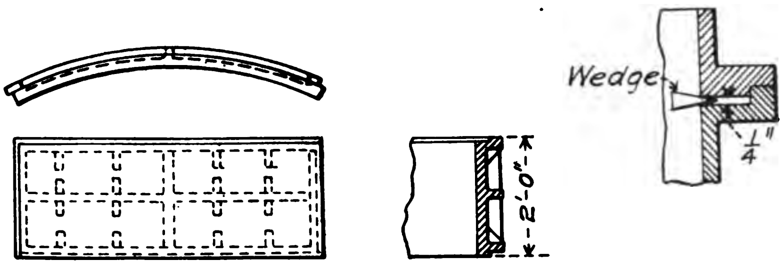


Fig. 56. — English Tubbing Segment — 15 to Circumference

English segments, however, have rough edges and no bolts and are made water-tight by wedging the cracks with wood, whereas the German have machined edges provided with flanges and are bolted together. Lead gaskets are used to make a tight joint. English segments are about 2 ft. and German about 5 ft. high.

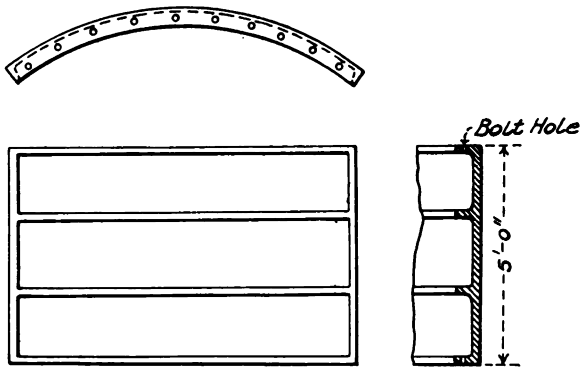


Fig. 57. — German Tubbing Segment — 8 to Circumference

The process of setting a wedging curb and building up English tubbing in wet rock is described by Mr. J. J. Prest as follows:

"The shaft was sunk about 9 or 10 ft. into the impermeable stratum, of the full diameter of, say, 23 ft., and then decreased abruptly to the finished size of the shaft, say 20 ft., and the sinking was continued a further distance of 6 or 8 ft. The cradle (walling scaffold) was then lowered

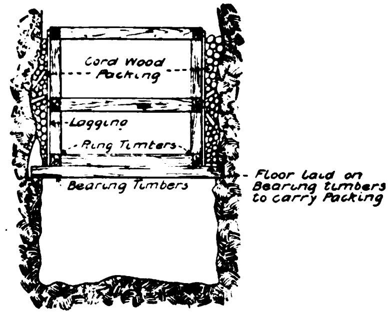


FIG. 58

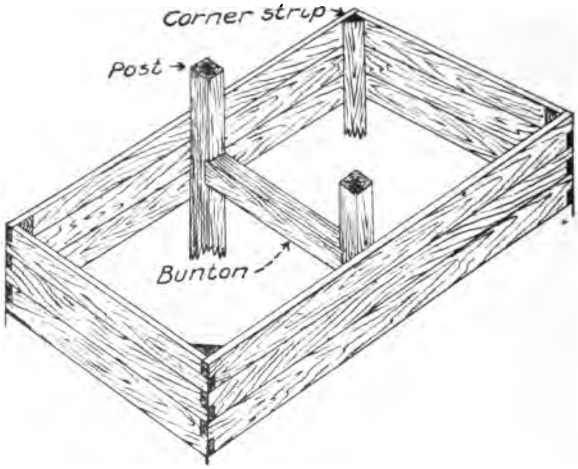


FIG. 58a. — Timber Sketches

into the pit bottom and a temporary wood water-ring was fixed on dowels about 9 or 10 ft. above the site selected for the bed of the wedging curb. The whole of the water running from the sides of the shaft was then collected in this temporary water-ring and allowed to run off in canvas hogges or trunks at two or three different positions to the pumps.

"The cradle having been fixed in position, the sinkers proceeded to level the surface of the rock bed with mattocks, and when this was accomplished to the satisfaction of the engineer, a wedging curb, three segments of which were fitted with valves to pass gas or air accumulated behind the tubbing, was laid on the bare rock, seasoned red-wood sheeting $\frac{3}{8}$ in. thick was placed between all end joints, and the spaces between the back of the curb and the rock were filled with dry-wood gluts to bring the inside of the curb up to the finished diameter of the shaft. Afterwards well-seasoned tapered dry-wood wedges were driven into the wood packing between the back of the curb and the strata until steel chisel points refused to enter. Then a layer of $\frac{3}{8}$-in. horizontal sheeting was placed on the top of the wedging curb, and the 2-ft. foundation course of tubbing was put on, breaking joints with the curb, $\frac{3}{8}$-in. red-wood sheeting being placed between the end and horizontal joints, and the course was brought up to the correct radius of the shaft by means of wood packing. Next one or two courses of plain tubbing were put on, the fourth course usually containing three or more special segments (technically termed 'valve-segments'), cast with holes 4 to 6 in. in diameter in the center, with the object of permitting the water to pass from the back to the front side of the tubbing, and so to the pumps, when the temporary wood water-ring was removed.

"The next operation was to wedge lightly the vertical joints of the three or four courses of tubbing, and to run the whole up solid with good cement grout. The temporary water-ring was then removed, and additional courses of ordinary tubbing were built on, to a total height of about 60 ft. The joints were now lightly wedged, commencing from the top with the vertical joints, and from the bottom with the horizontal seams, using red-wood wedges. Additional courses of segments of suitable height being used to close up to the wedging curb above, the vertical and horizontal seams were again twice wedged alternately as before, and the small center holes in each segment were

plugged. Finally the large holes in the valve segments passing the feeders were plugged simultaneously with long tapered plugs of wood, the excess being sawn off flush with the front side of the orifice, the cast-iron caps were bolted on to the flanges and the shafts was rendered dry if the work had been well carried out."

German tubbing is started from a wedging curb and is bolted together as built up. When the rock itself is treacherous as well as wet, under-hanging tubbing is sometimes employed. In this case a wedging curb, faced on the bottom and provided with bolt holes, is set just above the shaft bottom. The segments are lowered to the bottom, and are grasped one at a time with a special pair of tongs and raised to the under side of the curb. Each segment is then suspended by two bolts with long threads and the tongs are removed. The lead gasket is inserted; the segment is raised to place by screwing up the nuts on the long bolts, and is then bolted up tight. The process is repeated as soon as the shaft has been deepened sufficiently. After each ring has been bolted up, the opening at the bottom between it and the rock is closed with plates and wedges, and the space behind is filled with cement grout poured in through holes in the segments.

CHAPTER X

Concrete Linings. Costs Per Linear Foot for Rectangular, Elliptical, and Quadrilateral Shafts

Two types of concreted shafts are to be considered: the circular or elliptical, with unsupported lining; and the rectangular, with reinforced concrete lining supported by steel beams, concrete buntons, or walls. In both, the concrete is placed directly against the rock walls and an inner form only is required. From a construction standpoint the types are equally feasible, and the choice depends upon the cost. In several cases known to the writer a compromise has been effected by shaping the shaft as a quadrilateral with sides formed of circular arcs.

For a single compartment air shaft the circular shape is in every way the most desirable, not only because the circular shaft is cheaper to sink than a square shaft of equal area, but also because a circular ring of plain concrete is the strongest lining possible with a given amount of material.

In the case of a shaft with two or more compartments, the selection of the most economical shape requires some calculation. At first sight it would seem that a simple rectangular shaft, surrounded by a concrete wall only thick enough to be as strong as the usual timber lining, would be a satisfactory, as well as a cheap, shape, but this is not the case. A concrete lining, even when provided with weep holes, must resist some hydrostatic pressure; a timber lining has none to resist. Furthermore, permanent weep holes are most undesirable; the concrete should exclude the water entirely, and hence must be designed to bear very great pressure at considerable depth. Just what amount the theoretical pressure is reduced by the adhesion of the

concrete to the shaft walls and by the blocking of the fissures with grout cannot be calculated. In solid rock, where the

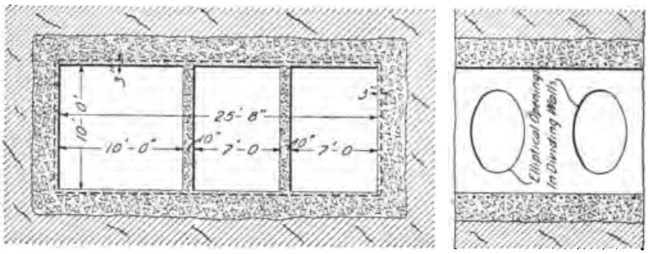


FIG. 59. — Rectangular Concrete Lined Shaft

water enters in well-defined springs, the proper grouting of the springs will relieve the lining of all pressure. In very

TABLE 1. QUANTITIES AND COSTS OF RECTANGULAR SHAFT

Depth in feet	20	50	100	150	200
Total thickness of lining in inches	14	21	28	34	39
Quantities per linear foot:					
Concrete to neat line in cu. yds.	3.90	5.70	7.60	9.30	10.70
Concrete, actual in cu. yds.	5.80	7.70	9.70	11.50	13.00
Excavation to neat line in cu. yds.	12.80	14.60	16.50	18.20	19.70
Excavation, actual in cu. yds.	14.70	16.60	18.60	20.40	22.00
Weight reinforcing steel in pounds	256	443	650	845	1,030
Costs per linear foot:					
Forms	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00
Concrete at $5 cu. yd.	29.00	38.50	48.50	57.50	65.00
Excavation (see note *)	49.60	53.20	57.00	60.40	63.40
Reinforcing steel at $.02 lb.	5.10	8.90	13.0	16.90	20.60
Total	$108.70	$125.60	$143.50	$159.80	$174.00

seamy rock, on the other hand, the lining may have to bear parctically the full hydrostatic pressure.

In order to compare the costs of the different shapes, let

* NOTE. — Cost of excavation figured on basis of $4 per cubic yard for section containing 12 yards per linear foot; additional excavation at $2 per cubic yard. Thus, cost of 16 cubic-yard section = 12 × $4 + 4 × $2 = $56. These unit costs are for purposes of comparison only and should not be used for estimating.

us consider in detail three designs for a shaft with two 7 × 10 ft. hoistways and an airway with an area of 100

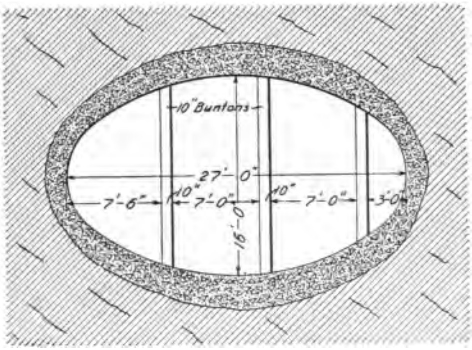


FIG. 60. — Elliptical Concrete Lined Shaft

sq. ft. As the whole area of a hoist shaft is ordinarily used for the passage of air, the size of the air compartment

TABLE 2. QUANTITIES AND COSTS OF ELLIPTICAL SHAFT

Depth in feet,	0 to 100	150	200	250	300	400
Thickness of lining in inches, ends	12	12	12	12	12	12
Thickness of lining in inches, sides	12	18	24	29	34	42
Quantities per linear foot:						
Concrete to neat line, cu. yds.	2.60	3.40	4.30	5.00	5.70	6.80
Concrete, actual in cu. yds.	4.40	5.20	6.10	6.80	7.50	8.60
Excavation to neat line in cu. yds.	15.20	16.00	16.90	17.60	18.30	19.40
Excavation, actual in cu. yds.	17.00	17.80	18.70	19.40	20.10	21.20
Costs per linear foot:						
Forms	$15.00	$15.00	$15.00	$15.00	$15.00	$15.00
Concrete at $5 cu. yd.	22.00	26.00	30.50	34.00	37.50	43.00
Excavation (see note*)	54.40	56.00	57.80	59.20	60.60	62.80
Total	$91.40	$97.00	$103.30	$108.20	$113.10	$120.80

may be reduced if the rest of the shaft is enlarged; the airway must, however, be large enough to contain pipes and

ladders and to provide in addition an ample passage for air if the hoistways are temporarily closed.

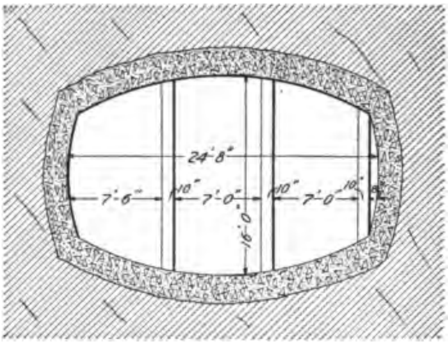


FIG. 61. — Quadrilateral Shaft

Let us assume a minimum thickness of 12 in. of concrete for a water-tight lining; also that in each case the lining

TABLE 3. QUANTITIES AND COSTS OF QUADRILATERAL SHAFT

Depth in feet	0 to 100	150	200	250	300	400
Thickness of lining in inches	12	19	26	32	39	52
Quantities per linear foot:						
Concrete to neat line in cu. yds.	2.70	4.40	6.20	7.90	9.90	13.90
Concrete, actual in cu. yds.	4.50	6.30	8.20	10.00	12.10	16.20
Excavation to neat line in cu. yds.	14.90	16.60	18.40	20.10	22.10	26.10
Excavation, actual in cu. yds.	16.70	18.50	20.40	22.20	24.30	28.40
Costs per linear foot:						
Forms	$15.00	$15.00	$15.00	$15.00	$15.00	$15.00
Concrete at $5 cu. yd.	22.50	31.50	41.00	50.00	60.50	81.00
Excavation (see note*)	53.80	57.20	60.80	64.20	68.20	76.20
Total	$91.30	$103.70	$116.80	$129.20	$143.70	$172.20

carries the entire hydrostatic pressure; then the specifications for the three forms of shafts will be as follows:

Rectangular Shaft. — Fig. 59. Two hoistways, 7 × 10 ft.;

one airway, 10 × 10 ft. Ten-inch concrete dividing walls in place of buntons. Extreme inside dimensions, 10 × 25 ft. 8 in. Area airway, 100-sq. ft.; total clear area, 240 sq. ft. Thickness of lining at any point made equal to depth of simple beam of 10-ft. span required to sustain hydrostatic pressure at that point. Resisting moment and weight of reinforcement calculated by Johnson's formula, factor of safety 3. (Ultimate tensile strength of steel, 65,000 lbs. per square inch, compressive strength of concrete in beam, 2500 per square inch.) Reinforcing steel set 3 in. inside of face of wall.

Cost of forms, Table 1, includes cost of forms for dividing walls, and is therefore greater than the cost in the elliptical shafts.

Excess of actual over theoretical quantity of excavation is estimated as 15 per cent. for 28-ft. shaft. This excess increases with the length of the shaft only, as the ends are drilled to line.

Elliptical Shaft. — Fig. 60. Extreme inside dimensions, 16 × 27 ft. Area of airway, 78 sq. ft. Total clear area, allowing for 10-in. buntons, 304 sq. ft.

Strength of lining calculated on the assumption that the stress in the elliptical cylinder at any point is equal to that caused in a circular cylinder, with a radius equal to the radius of curvature of the ellipse at the given point, by the same hydrostatic pressure acting upon it. The lining is therefore made thicker at the sides than at the ends.

To prove this proposition, assume the lining to be constructed of a number of small portions, each the arc of a circle. The stress in each portion caused by the hydrostatic pressure of the film of water between it and the rock is directly proportional to the radius, and the thickness of each section should therefore be made proportional to the radius. Considering any portion, as *a-b*, Fig. 62, the skewback toward the side of the ellipse is formed entirely by the adjoining portion, while the skewback toward the end is formed partly by the adjoining portion and partly by the

rock. If the number of circular portions is indefinitely increased, the unbalanced end thrust of each will be taken up by the irregularities of the rock.

Ultimate compressive strength of concrete, 3000 lbs. per square inch; factor of safety, 3.

Excess of actual over theoretical excavation assumed as 12 per cent. for smallest section. As the length of the shaft does not vary, this excess is constant.

Quadrilateral Shaft. — Fig. 55. Inside dimensions, 16 × 24 ft. 8 in. Radius of ends and sides, 23 ft. Area of airway, 94 sq. ft. Total clear area, allowing for 10-in. buntons, 294 sq. ft.

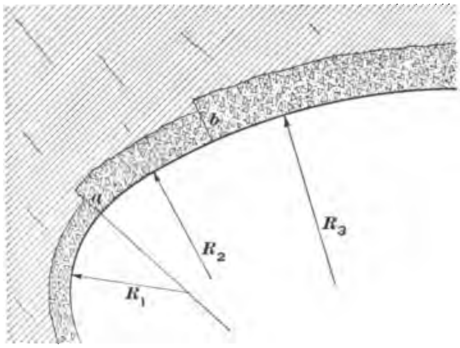


FIG. 62

For calculating stresses, sides and ends are considered as portions of a 46-ft. circular cylinder. Ultimate compressive strength of concrete, 3000 lbs. per square inch; factor of safety, 3.

Excess of actual over theoretical quantity of excavation assumed to be 12 per cent. for minimum length and to increase with the length.

Methods of Working. — The easiest way to concrete a shaft is to finish sinking, then start at the bottom and build up. Unfortunately this is feasible only for comparatively shallow shafts in hard dry rocks, and, ordinarily, successive lengths of lining must be placed as the shaft deepens, to protect the sides and cut off feeders of water.

When the shaft has been sunk as far as seems safe or desirable, hitches are cut in the sides, a set of bearing timbers is placed and a heavy plank floor laid upon them to support the concrete. In order to avoid injury to the concrete when sinking is resumed, the platform should be built 15 or 20 ft. above the shaft bottom. It is cheapest to cut the hitches near the bottom when the shaft is at the proper depth and then to sink three or four cuts further; scaffolding is thus made unnecessary as it is easy to place timbers in hitches already prepared. In a rectangular or elliptical shaft transverse bearing timbers are placed; in a circular shaft four timbers placed in the form of a square make the best platform. In any case an opening should be left in the bucket way so that the bottom is accessible.

Forms are started from the platform and are built in rings 5 to 10 ft. high. When each ring of forms is completed a temporary floor is laid on top of it. Concrete mixed at the top of the shaft is lowered in shaft buckets and dumped on the floor, whence it is shoveled behind the forms. To prevent loss of concrete the floor must be laid with tight joints, and this is most easily accomplished by making it in sections as large as can be lowered into the shaft. Another plan is to dump the concrete from the bucket into the forms direct through a movable chute; the necessity for laying the tight floor is thus obviated.

A $\frac{1}{2}$-yd. batch mixer (such as the Smith or Ransome) gives the best results. One-half yard of wet concrete is about all an ordinary shaft bucket will hold without spilling. The use of a batch mixer makes it possible to use only one bucket without losing time, as a batch is being lowered and dumped while the next is being mixed. The mixer should if possible be set below the ground level (see Fig. 63) to avoid elevating the materials. Below the mixer a platform is placed for supporting the bucket while it is being filled. This platform should be 3 ft. wide and so situated that a bucket hanging free on the rope will clear it 10 or 12 in., and should be provided with a hand rail except for

4 ft. immediately in front of the mixer. When concreting, two men stand on the platform, one on either side; the empty bucket is hoisted slightly above the platform level, is grasped

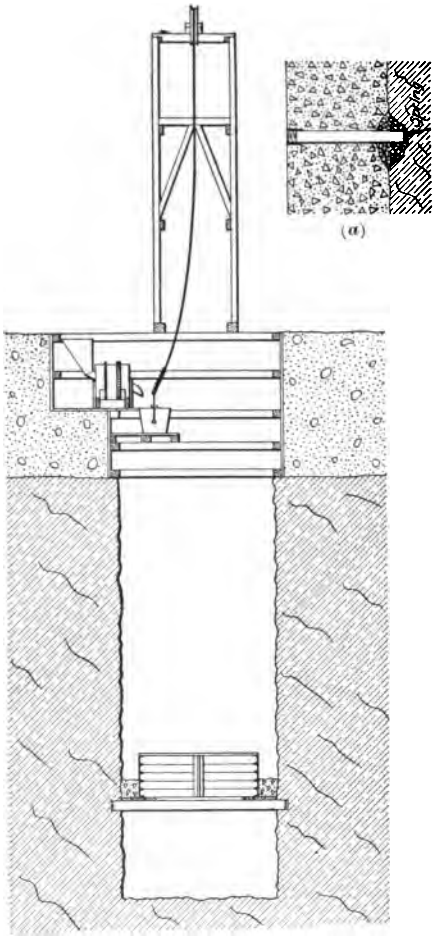


FIG. 63. — Lowering and Placing Concrete

by the two men and swung in under the discharge chute of the mixer, and is then lowered. When filled it is hoisted slightly, swings out over the shaft and is steadied by the men on the platform before being lowered.

By working as outlined above with a good organization it is easy to place 12 or 15 one-half yard batches per hour, and a shaft lining containing as much as 6 yds. of concrete per linear foot can thus be placed at the rate of more than a foot an hour — about as fast as timber. It is the time required to construct the foundation platform, to set the forms, and to connect a new section of lining to the one above it that makes the process slow.

Foundation platforms must be built and closures must be made; time can be saved only by reducing the number. Plenty of forms should therefore be provided, and the sections made as long as possible. The design of forms, both as regards strength and finish and facility of erection, demands careful consideration.

Forms. — The writer has had experience with three types of forms. The first, consisting of wooden slabs, was used for lining a 17 × 33 ft. elliptical shaft at Tug River, W. Va. (*Engineering News*, November 7, 1904). The slabs were made of 2-in. vertical lagging planks nailed top and bottom to double 2 × 12 in. centers. They were 5 ft. high, and 8 slabs made up a complete ring. These forms made a satisfactory wall, but were heavy and were greatly damaged by moving. Eight to ten hours were required to set one ring; the work was divided into two shifts, one setting forms and one concreting, so the progress made was only 5 ft. per day.

The second type, consisting of steel slabs, was used on several waterway shafts on the Catskill Aqueduct. These shafts are circular, about 14 ft. 6 in. in finished diameter, and a perfectly smooth surface is required. The slabs are 5 ft. high and are made four to a ring. Forty feet of forms were provided for each shaft. Two rings were erected at a time, the concrete being tamped and spaded with long-handled tools, and when new it was possible to erect and fill two rings in twelve hours. With use the forms become more difficult to set: the progress, including platforms and closures, averaged 10 ft. per day. A pair of wooden key

blocks is provided at opposite joints in each ring. These are chopped out to release the forms.

After a section of lining is finished, the steel slabs are usually left in place until the next section is ready and then moved down, a ring at a time. If the section to be concreted is longer than the available forms, a working platform may be suspended below the forms with ropes and the slabs taken off at the bottom and moved up. The slabs should always be cleaned and oiled before being used again.

The third type consists of angle-iron rings spaced 4-ft. centers and lagged with vertical 2-in. plank. Wooden nailing strips are bolted to the angles. These forms, although they make a surface inferior to the steel forms, are cheaper and easier to place. One ring at a time is set and filled, and by working continuously four or five can be completed in twenty-four hours. These forms are removed, taken to the surface and cleaned after each section of lining is finished.

Placing. — Concrete should be mixed wet, even though considerable water is present in the shaft, and should be thoroughly spaded next the forms. Springs of any volume appearing in a section that is to be lined should be taken care of in advance of the lining: this can be done by drilling a hole into the water-bearing seam, inserting a pipe long enough to carry the water out into the shaft, and caulking around the pipe. All springs should be piped through the forms into the shaft before concrete is placed, Fig. 63*a*, for if this precaution is neglected a very slight inflow may accumulate enough head to disrupt the green concrete and cave in the forms. The writer has known this to actually happen and has had to dig out about 80 sq. ft. of lining displaced in this way by the water from one tiny spring.

Grouting.*— The drainage pipes should be provided at the inner ends with sleeves set flush with the face of the wall. If the concrete has been properly placed and too much water has not been encountered, the shaft can be made dry by plugging the sleeves. If, however, the concrete is porous,

* See Appendix A.

it may be necessary to force grout through the pipes until all crevices are filled. The grout is mixed very thin, and can be pumped in with a high-pressure pump or expelled from a tank and driven into the pipe by the use of high-pressure compressed air. Concrete can be made absolutely water-tight in this way if enough grout pipes are provided.

In closing, the writer wishes to express his gratitude to Mr. Evan Edwards, of Scranton, whose knowledge of practical shaft sinking has been of the greatest assistance in the preparation of this book.

APPENDIX A

Grouting Shafts 4 and 24, New York City Aqueduct

SHAFT 4

Shaft 4 is concrete-lined circular shaft sunk through the Fordham Gneiss near Jerome Park Reservoir. The depth to tunnel invert is 242 ft.; the finished diameter of the concrete lining is 14′ 0″, and the effective average thickness of the lining in normal rock is 13″. Sinking progressed without incident on the "one drilling and two mucking shift" plan until a depth of 149 feet was reached; in the first round drilled below this depth clear water was found in four of the thirty holes. The rock was solid and each hole was plugged with a wooden plug wrapped in sacking as soon as the bottom was reached.

It was thought that the water might be only a pocket, so after a proper pump had been placed one of the plugs was removed. Pumping was continued for two weeks, during which time the upper part of the shaft was lined and appliances for grouting obtained. As the flow was not appreciably diminished, it was then decided to grout the water-bearing crevice through the drill holes.

The grout mixer, which was of the air stirring type standard on the aqueduct, was lowered to the shaft bottom and coupled to the air line, and was then connected successively to the various wet holes. In order to make connections, pieces of 2-inch pipe 3 feet long with standard threads at one end were given a gradual taper at the other; as soon as a plug was drawn from a hole the tapered end of the pipe was wrapped with sacking and driven in tight, and a 2-inch stop cock screwed on. The mixer was attached to the holes by a heavy hose. The first series of holes was

grouted in one shift; the next day more holes were drilled and more clear water met with, and grouting was resumed that night. After 12 hours the holes refused to take any more grout, and operations were discontinued for 24 hours. Regular sinking was then resumed and no more water was met for a week. About 200 sacks of neat cement were used in blocking this fissure.

At a depth of 181 feet the water was again found in the sump holes, and grouting was once more necessary. This time the water was heavily charged with sand and pieces of disintegrated rock; the rock around the collars of the drill holes was seamy and it was harder both to make good connections and to force grout into the holes after the connections were made. Grouting was nevertheless persisted in and in three weeks 130 holes from 10 to 20 feet deep were drilled in the shaft bottom, and over 50 cubic yards of grout (mostly neat cement) was forced into the fissures at pressures up to 240 pounds per square inch. Almost every hole drilled met some water, and the usual procedure was to drill five or six holes, grout them, lay off a shift or two to permit the grout to set, and then to drill five or six more holes. The depth at which water was met gradually increased, and it was therefore possible to sink four feet during the three weeks of grouting. The leakage over the shaft bottom, however, gradually increased to 85 gallons a minute.

At the end of this period the shaft bottom was so thoroughly perforated that there was no sound rock left to drill into and, after an unsuccessful attempt to stop the leakage with a concrete blanket, sinking was resumed. It was found in passing through that the disintegrated area was a band varying from 1 to 5 feet in width, circling the shaft, 10 feet higher on the east than on the west side and twisted and folded in every direction. Below this was solid and perfectly sound rock.

The sand was compacted so thoroughly by the pressure

to which it had been subjected that it showed no tendency to wash out, and the flow into the shaft did not appreciably increase.

After excavating 10 feet below into the solid rock, the shaft was concreted; a special section with a minimum of 24 inches of concrete was placed for 20 feet, extending into the solid rock above and below. Reinforcing steel, consisting of 1-inch rods, 24 inches apart, vertically and horizontally, was placed 18 inches from the face to prevent cracking. The disintegrated area was first lined with thin sheet iron and the water was led through the forms before concreting. The space back of this sheet iron was packed with rock. Five days after concreting the holes were plugged, and the gauge showed 77 pounds per square inch pressure back of the lining. The leakage through the concrete after the holes were plugged was only one or two gallons per minute. When the concrete had set for a month this leakage was entirely cut off by grouting the holes.

SHAFT 24

Shaft 24 is of the same general construction as Shaft 4 and penetrates blocky and seamy granodiorite for its entire depth in the rock, Elevation–76 to Elevation–269. At intervals horizontal seams were encountered generally $\frac{1}{4}$ inch to $\frac{1}{2}$ inch thick which were filled with finely crushed rock that allowed water to flow into the shaft, usually in only one point of the seam. As the seams were encountered holes were drilled into them 2 or 3 feet deep wherever there was any leakage and when the shaft was concreted these holes were fitted with grout pipes and were grouted. No great quantity of water was met with until at Elevation-221, while drilling a round, a flow of 240 gallons a minute was struck, all the water coming out of one hole. This water was under the full hydrostatic pressure due to the head and flooded the shaft. After about a week's delay, in which

time large pumps were obtained, the shaft was emptied. Grouting was then commenced, using the same general methods as were used at Shaft 4. In all, 10 holes were drilled and 75 cubic yards of neat cement grouting was pumped in under pressures up to 400 pounds per square inch. The leakage into the shaft was reduced by this grouting to about 25 gallons per minute.

APPENDIX B

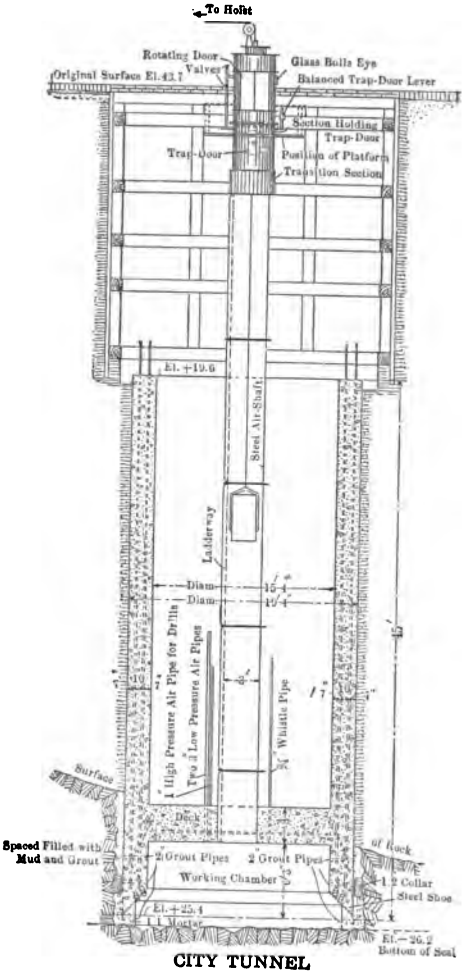
Several of the shafts of the City Aqueduct on the lower east side of Manhattan Island and in Brooklyn were sunk through great depths of water-bearing sand by the pneumatic caisson method. The caissons are of two sizes, 15 feet 4 inches and 18 feet in diameter, and 2 feet and 3 feet thick respectively, and are heavily reinforced with vertical and horizontal rods. At the bottom of each a heavy steel shoe is imbedded to form a cutting edge. The vertical reinforcing rods are attached to the shoe. The roof of the working chamber is formed by a heavy reinforced concrete deck with two openings, to which the air shafts for the man lock and for the material lock are connected.

Each shaft chamber was first excavated and timbered square to about the ground water level, and the caisson was then started from the bottom of the chamber and built up to the full height before sinking. Steel forms were used throughout. The deepest caisson projected over 60 feet above the ground before sinking was started.

Excavated material was handled by a stiff-leg derrick. The caisson was loaded with pig iron, and the space between the shafting and the concrete filled with excavated sand for additional weight. Sinking proceeded rapidly in three shifts, at one of the shafts rock being reached through 55 feet of sand in five days.

The most difficult part of the operation is the sealing of the caisson into the rock, so that the air can be safely taken off. To accomplish this the ledge is leveled off and the rock excavated for several feet, the caisson meanwhile being supported on timber posts. The rock is then thoroughly cleaned with high pressure air, a one-to-two mortar collar is built around the shaft $\frac{1}{8}$ of an inch back of the

outer edge of the shoe, and the posts are then shot out, allowing the caisson to sink through the collar into its final



CITY TUNNEL
Compressed Air Caisson
Appendix B

0 2 4 6 8 10 ft.

position. The space between the collar and the caisson is then grouted through pipes previously set in the collar.

INDEX